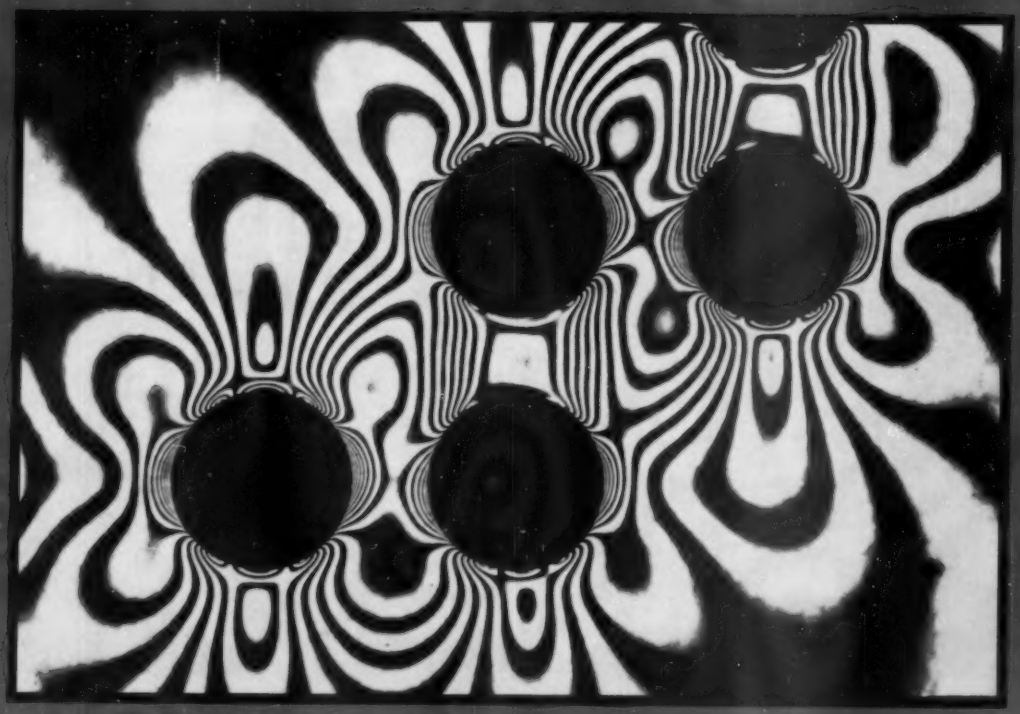
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

October 1956



A plastic model of a reactor vessel which when loaded to stimulate strains of a working vessel revealed above pattern of stress concentrations.

Power Trends and Boiler Feed Pumps

Soot Ignition Temperature

Measuring Gas Temperatures

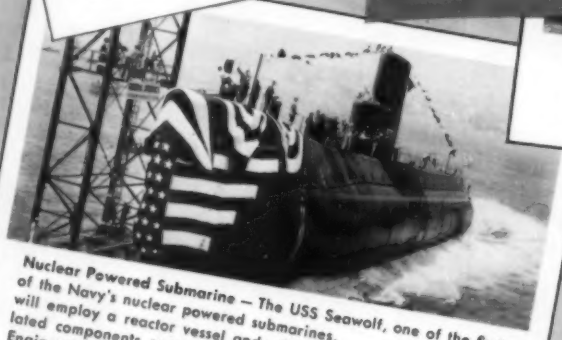
Plant Stack Stability

MILESTONES OF PROGRESS

Highest Marine Steam Temperature — The SS Atlantic Seaman, one of three sister ships, is equipped with C-E Boilers designed to produce steam at 1020F — highest in Marine service.

. . . afloat

Highest Marine Steam Pressure — The SS Venore, one of a class of eight ocean going ore carriers, is equipped with C-E Boilers designed to operate at a steam pressure of 1450 psig — highest in Marine service.



Nuclear Powered Submarine — The USS Seawolf, one of the first of the Navy's nuclear powered submarines, will employ a reactor vessel and other related components supplied by Combustion Engineering.

and ashore

Highest Temperature, Highest Pressure — Ashore — Two C-E Controlled Circulation Boilers at the Kearny Station of Public Service Electric and Gas Company were the first utility boilers to be placed in service for steam conditions as high as 1100F at 2350 psig. Highest pressure and temperature projected to date will be 5000 psi and 1200F — a C-E Supercritical Boiler for Eddystone Plant of Philadelphia Electric Company.

• Combustion Engineering has long been identified with advanced standards of power practice — afloat and ashore. That's why you can expect top performance when you buy C-E Boilers.

C-E

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 28 **No. 4**

October 1956

Feature Articles

Steam Power Plant Trends and Their Effect on the Boiler Feed Pump—I ..... *by Igor J. Karassik* 36

Soot Ignition Temperature Measurement ..... *by D. R. Anderson and W. S. Watson* 43

Measurement of Gas Temperatures with Thermocouples ..... *by Richard C. Corey* 47

Devising a Test for Plant Stack Stability ..... *by Jack Smith* 57

Instrument Show Convenes In New York City 61

Combustion Symposium 61

Editorials

Tackling the Flyash Problem 35

One Way to Arouse Action 35

Departments

Advertising Index 74, 75

COMBUSTION published its annual index in the June issue and is indexed regularly by Engineering Index, Inc.

The magazine is now reproduced and distributed to libraries on microfilm by University Microfilms of Ann Arbor, Michigan.

GERALD S. CARRICK
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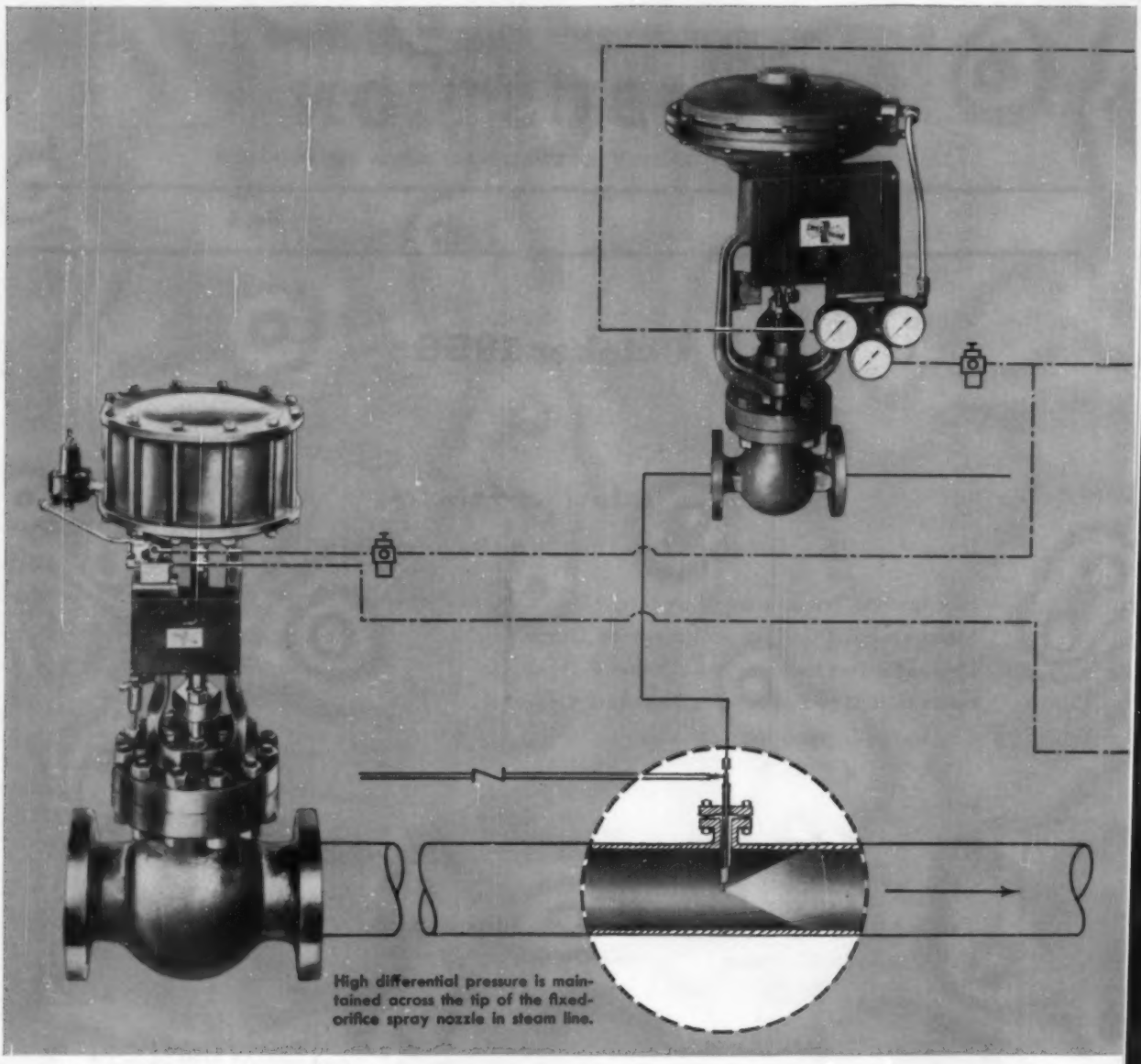
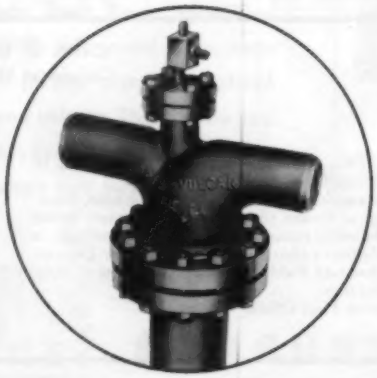
Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16
A SUBSIDIARY OF COMBUSTION ENGINEERING, INC.
Joseph V. Santry, Pres.; Charles McDonough, Vice-Pres.; Otto Strauss, Treas.; Thomas A. Ennis, Secy.
COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 500 rated boiler horsepower up and to consulting engineers in this field. To others the subscription rate, including postage, is $4 in the United States, $5.50 in Canada; and $8 in Latin America and other countries. Single copies: Domestic, 40 cents: Foreign, 60 cents plus postage. Copyright 1956 by Combustion Publishing Company, Inc. Publication Office, Easton, Pa. Issued the middle of the month of publication.
Acceptance under Section 34.64, P.L. & R., authorized by United States Post Office.

EPA

Printed in U. S. A.



High differential pressure is maintained across the tip of the fixed-orifice spray nozzle in steam line.



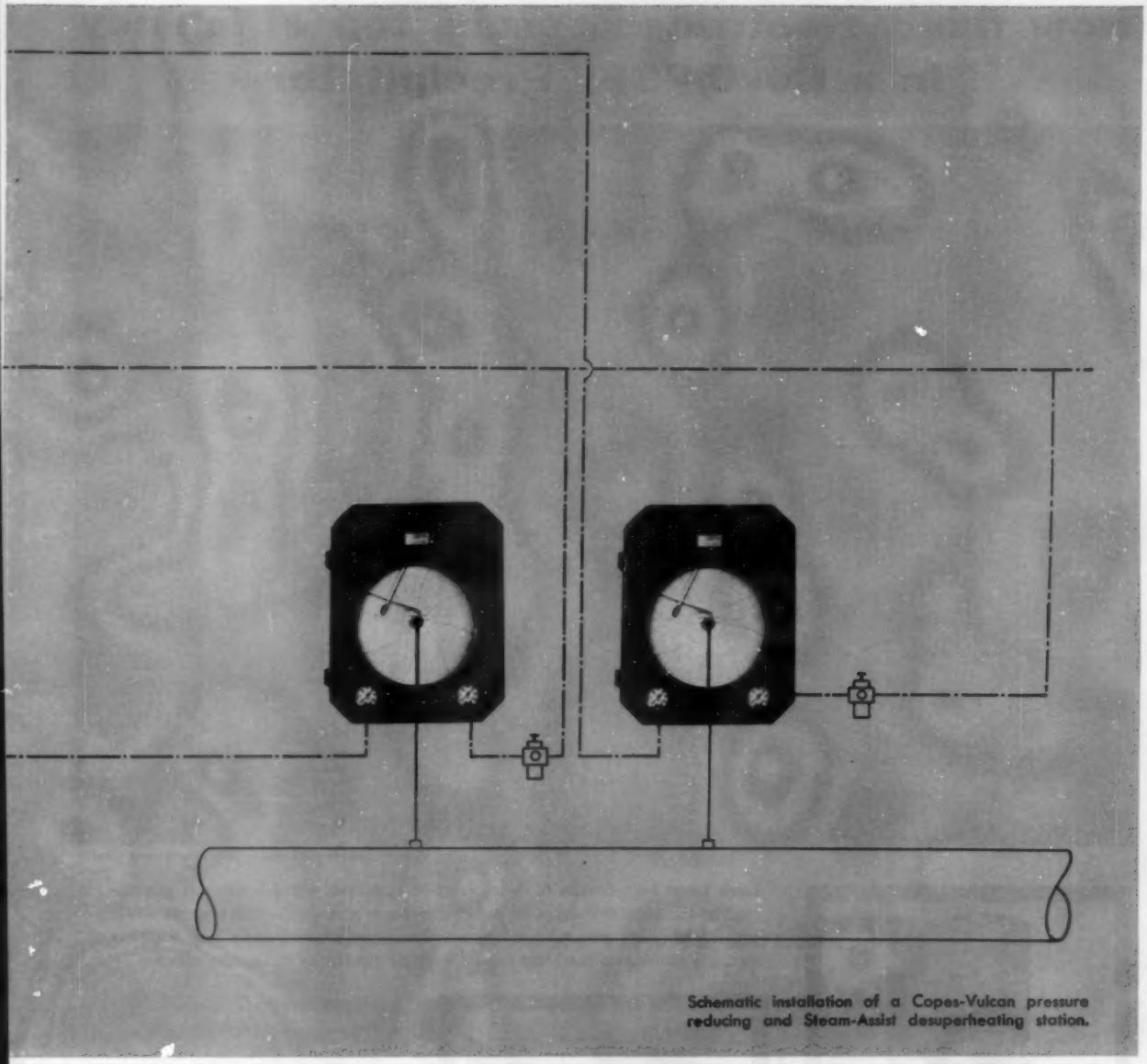
Copes-Vulcan offers in-line or carburetor type Steam-Assist, or simple mechanical-atomizing desuperheaters.

NEW Copes-Vulcan

These high-quality pressure reducing and desuperheating stations offer the latest advances in reducing valves and desuperheaters. They give you an integrated station designed specifically to meet your operating needs.

Copes-Vulcan valves—diaphragm or piston operated, depending on your conditions—give close modulating control. Simplified design means optimum operating characteristics with easy, low-cost maintenance.

The Steam-Assist Desuperheater advances a new principle in reducing steam temperatures. Cooling water and assisting steam are mixed in the exclusive



Schematic installation of a Copes-Vulcan pressure reducing and Steam-Assist desuperheating station.

Pressure Reducing and Desuperheating Stations

swirl chamber, upstream from the point of injection. No large steam bubbles form to cause hammer or vibration. Flow of assisting steam can be automatically reduced as load increases, and shut off completely at high loads where no more than mechanical atomization is needed.

"Packaged" control systems by Copes-Vulcan mean undivided responsibility, custom design and lifetime engineering service. They assure top performance over an unusually long service life.

50th Anniversary
BLAW-KNOX
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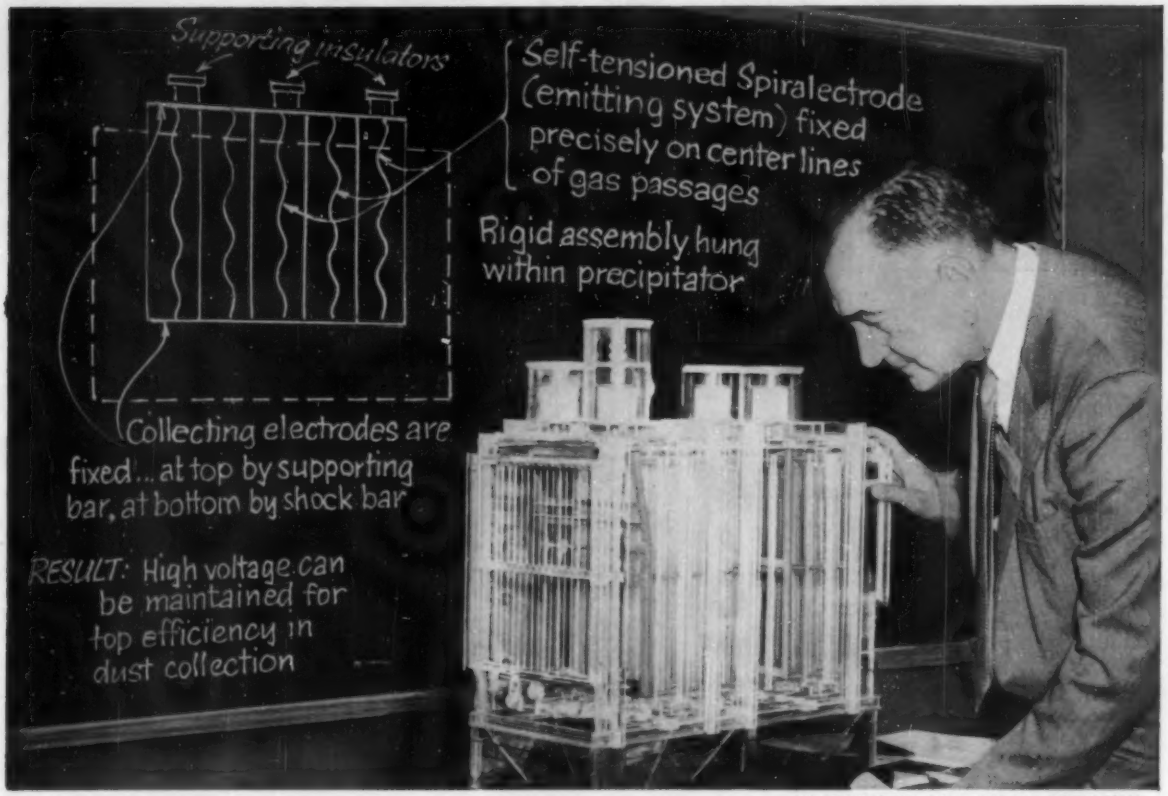
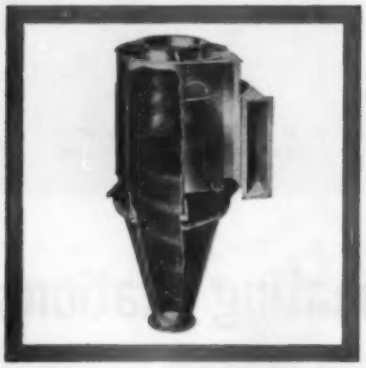
COPES VULCAN

How fixed electrodes assure top efficiency in a Buell "SF" Precipitator

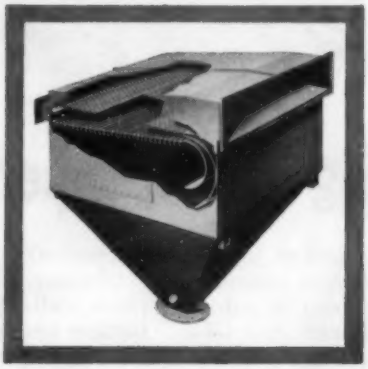

Supporting insulators
Self-tensioned Spiralectrode (emitting system) fixed precisely on center lines of gas passages
Rigid assembly hung within precipitator
Collecting electrodes are fixed... at top by supporting bar, at bottom by shock bar
RESULT: High voltage can be maintained for top efficiency in dust collection

PHOTOGRAPH OF BUELL PLASTIC MODEL BY INDUSTRY & POWER



Buell Cyclones also assure top efficiency with large diameter design to eliminate clogging . . . and by harnessing double-eddy and putting it to work.

Even when high-resistivity dusts must be collected, top efficiency is guaranteed by the exclusive shape of Buell's Spiralectrodes—proved to give 50-100% greater emission than straight wires. Exclusive Continuous Cycle Rapping virtually eliminates maintenance by keeping electrodes constantly clean.



Buell's Low Resistance Fly Ash Collector combines top efficiency to meet present strictness, with low draft loss for natural or mechanical installations.

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Nalco WATER TECHS

A paper on "A Laboratory Method for the Study of Steam Condensate Corrosion Inhibitors," presented at the 8th Annual Conference, National Association of Corrosion Engineers, has been reprinted by Nalco for distribution to men interested in this problem. Your copy will be sent free upon request.

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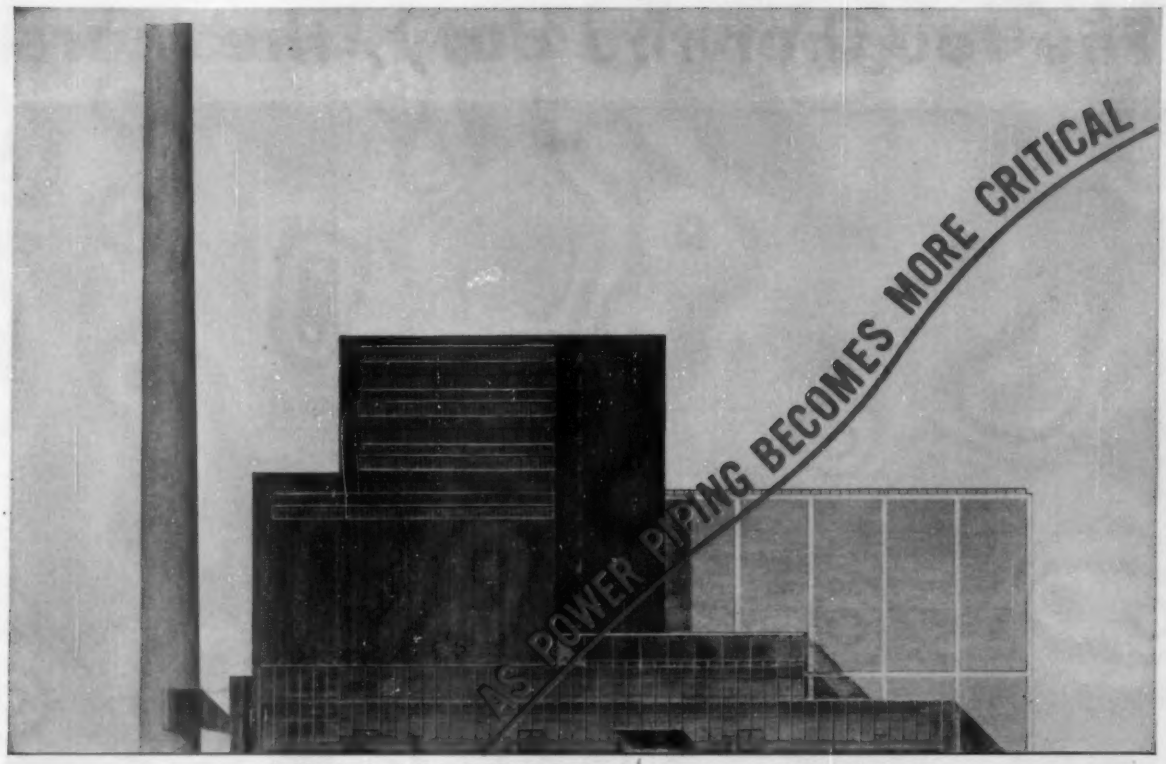

Architect's sketch of Philadelphia Electric Company's new Eddystone station

Kellogg's High Alloy Fabrication Keeps Pace

Designed to operate at 5000 psi at turbine throttle valve, and 1200 F., Unit No. 1 at Philadelphia Electric Company's new Eddystone station presented critical problems in the selection of an alloy for supercritical pressure piping, and in techniques for fabricating heavy-walled sections of this alloy in the shop and in the field.

More than a year ago, The M. W. Kellogg Company presented a comprehensive program to the Philadelphia Electric Company for selecting a suitable alloy, and since then has been working closely with this public utility and other prime contractors toward completion of the project. Numerous materials were studied, welded, tested, heat treated, and evaluated at Kellogg's Jersey City metallurgical laboratories. After many months of extensive and intensive work, Type 316 Stainless was selected. M. W. Kellogg has already perfected welding techniques, and is now continuing tests on this alloy and several other compositions, including strain aging for 1000 hours and 10,000 hours at 1300 F., to accumulate other data.

While this is the first time that Type 316 will have been used in power plant service for temperatures as high as 1200 F., and pressures as much as 5000 psi, it is by no means Kellogg's first experience with Type 316 or other stainless steels. For example, M. W. Kellogg recently undertook metallurgical studies and research for another large public utility prior to its selection of Type 316 for use at 1100 F. and 2400 psi. Kellogg also has done considerable fabrication of main steam lines and turbine leads, using Type 347.

The M. W. Kellogg Company welcomes the opportunity of discussing future power piping requirements with consulting engineers, engineers of power generating companies, and manufacturers of boilers, turbines, and allied equipment.

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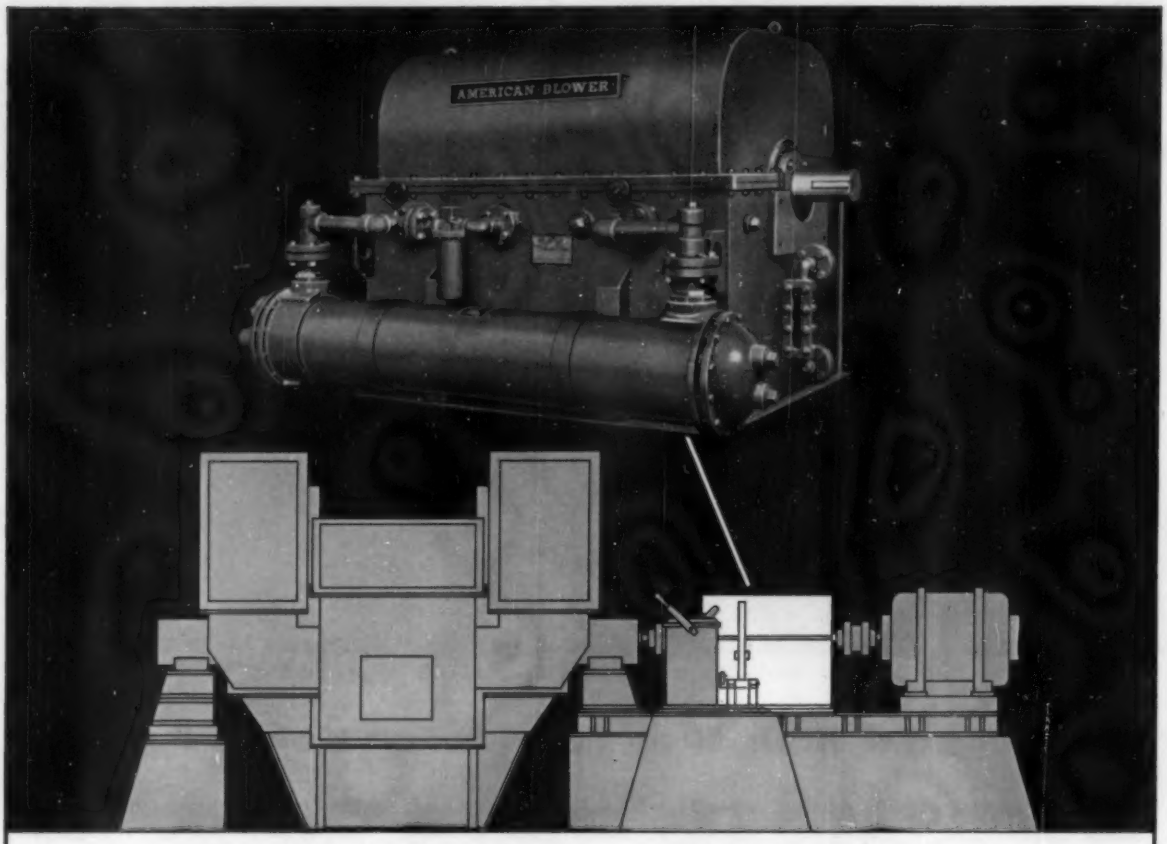
POWER PIPING—THE VITAL LINK

The tougher the duty, the more

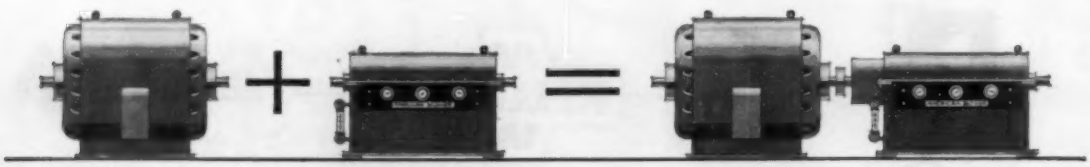


Mechanical Draft Fan Gýrol Fluid Drive Motor

LARGER MECHANICAL DRAFT FANS — Gýrol Fluid Drive gives you the kind of accurate, efficient control of mechanical draft that results in important power savings, longer equipment life. The reason: Fluid Drive's infinitely adjustable speed control, which enables each fan to operate at its optimum design or selection point.

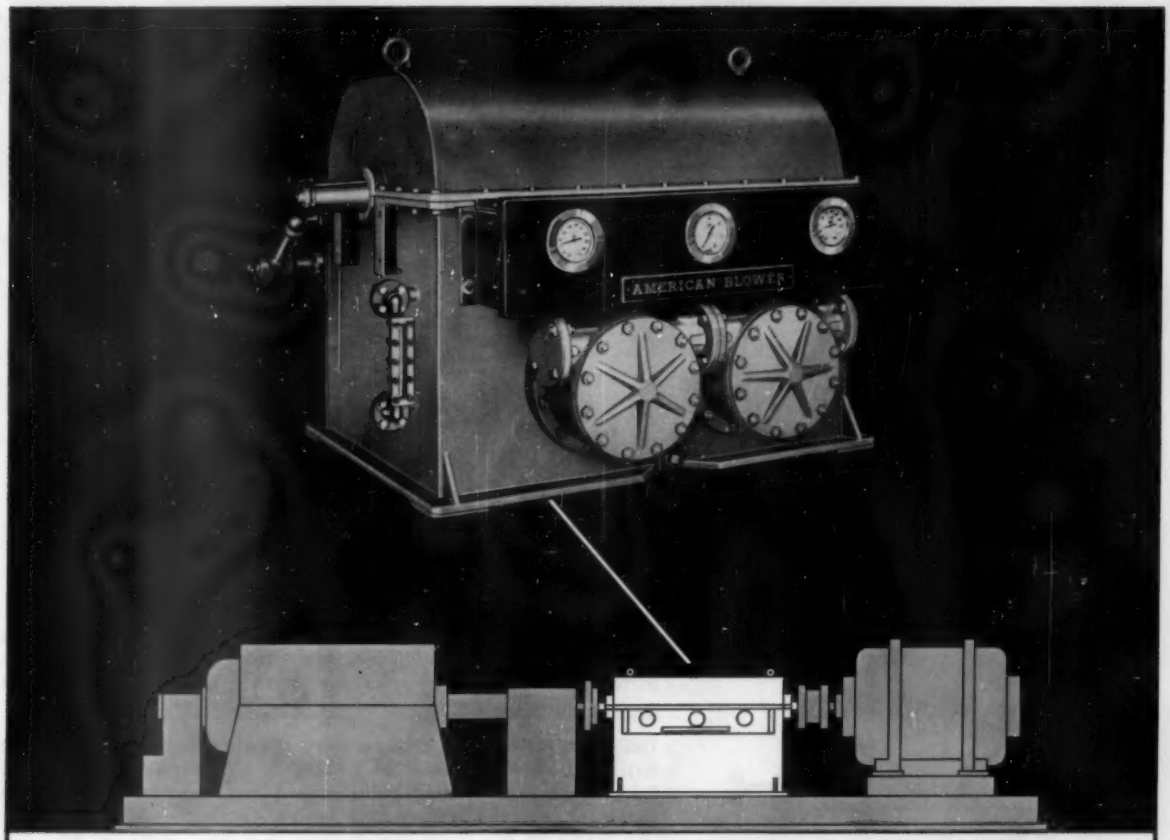
This adjustable-speed feature saves horsepower, gives good, stable volume and pressure control over the operating range . . . simplifies motor-starting equipment . . . reduces damaging high- and long-duration inrush currents on the motors . . . provides no-load starting of high WR^2s that exist in the new, high-volume, high-pressure fan wheels.

What's more, it prolongs life of fan bearings; reduces fly-ash abrasion on fan wheel, fan scroll, inlet boxes, and breeching connections. When you add to these advantages the reduction in noise level, it becomes increasingly clear that the tougher the duty, the more you need Gýrol Fluid Drive for control of mechanical draft.



Rugged constant-speed induction motor American Blower Gýrol Fluid Drive Smooth, adjustable-speed control

you need Gýrol® Fluid Drive



Boiler Feed Pump | Gýrol Fluid Drive | Motor

LARGER BOILER FEED PUMPS — As larger boiler feed pumps are built, there is a greater need for higher efficiencies and more accurate control. That's why more and more consulting and utility engineers are recommending Gýrol Fluid Drive.

You see, Gýrol Fluid Drive offers adjustable-speed pump control that saves power over the entire operating range by eliminating wasteful throttling. Then, too, Fluid Drive reduces wear on bearings and other vital parts by operating the pump at speeds that fit boiler demands. Paralleling of pumps is simplified. And emergency changeover from operating to standby pump is fast and foolproof—there's no need for boiler shutdown.

If your plant expansion calls for boiler feed pump control, it will pay you to talk to an American Blower engineer. He can show you where Gýrol Fluid Drive can save power, cut costs, give you a more efficient operation. Contact our nearest branch office, or write us direct. American Blower Corporation, Detroit 32, Michigan. In Canada: Canadian Sirocco Company, Ltd., Windsor, Ontario.

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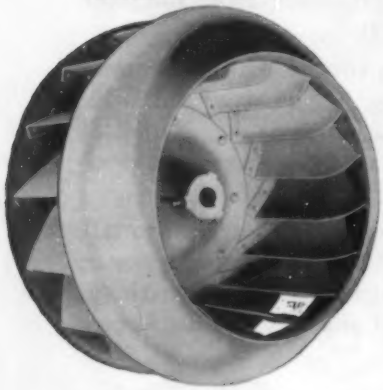
Smooth Divergent Flow



86% MECHANICAL EFFICIENCY — made possible by a combination of inlet, wheel and housing design. The smoothest "air-ride" in fan history.

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AVAILABLE in wheel diameters from 18¼" to 80¾", the new "Buffalo" "BLH" merits your consideration. Write for details on your company letterhead — today.

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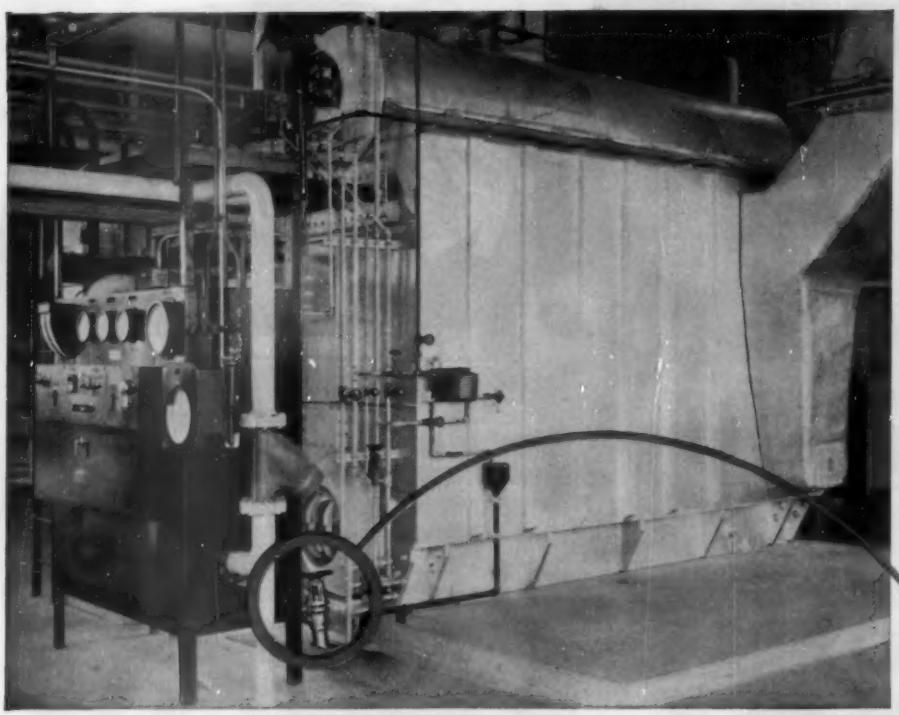

COMBUSTION ENGINEERING ADOPTS YARWAY SEATLESS BLOW-OFF VALVES FOR PACKAGE BOILERS

Combustion Engineering, Inc. on this package boiler installation at the Orangeburg Pipe Plant in California, again includes Yarway Seatless Blow-Off Valves as part of the "package."

It's a popular idea—and growing fast. All *good* package-type boiler installations are *better* when equipped with Yarway Seatless Blow-Off Valves.

More and more boilermakers are standardizing on Yarways, and more and more boiler users are expecting the advantages of Yarway Blow-Off Valves on their package units.

Get the full story on why more than 15,000 boiler plants use Yarway Blow-Off Valves, some for 30 to 40 years.

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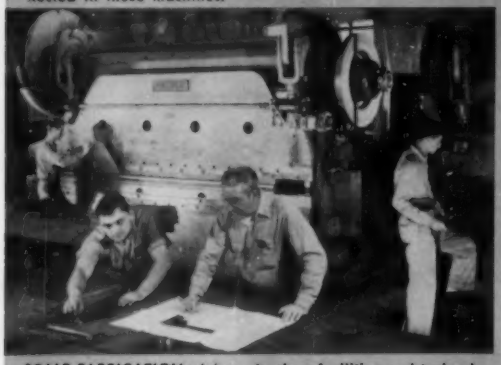
Yarway Type "B" Seatless Tandem Blow-Off Valve. Note balanced sliding plunger design with no seat to score, wear, clog or leak. Pressures to 400 psi.

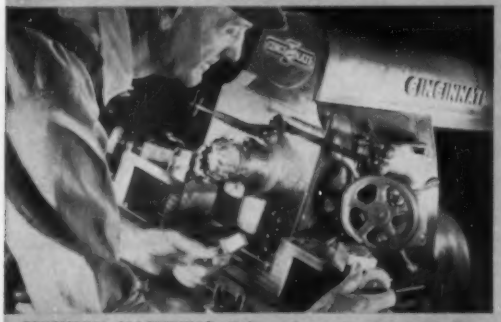
YARWAY **BLOW-OFF VALVES**

SOUND DESIGN—Richardson Engineers are career men in the design of automatic weighing equipment for all industries. Experience in thousands of field installations is reflected in these machines.



SCALE FABRICATION—Adequate shop facilities and trained workers are "musts" for the fabrication of a quality product.

WELDING—Good welds, like these, are the true test of high quality workmanship . . . can withstand the year in, year out impact of 'round-the-clock operation.

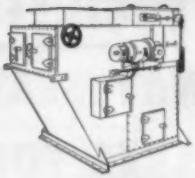


PRECISION MACHINING—Knife edges, the heart of the weigh beam insuring long-term accuracy and dependability, are produced on this modern milling machine.

What goes into a Richardson COAL SCALE

Besides COAL?

Here are evidences of the careful engineering and painstaking workmanship that go into every scale, every product manufactured by the Richardson Scale Company. Richardson stands behind its product . . . protects you with sound design, rugged, heavy-plate construction and competent nationwide service. That's why you can specify Richardson Automatic Coal Scales with complete confidence!



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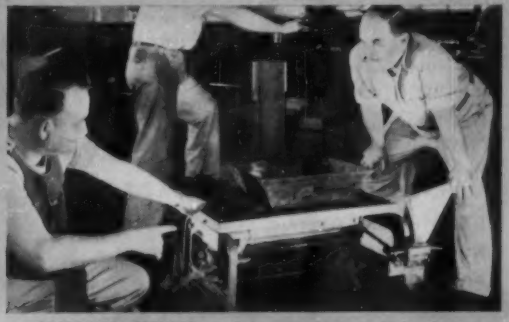

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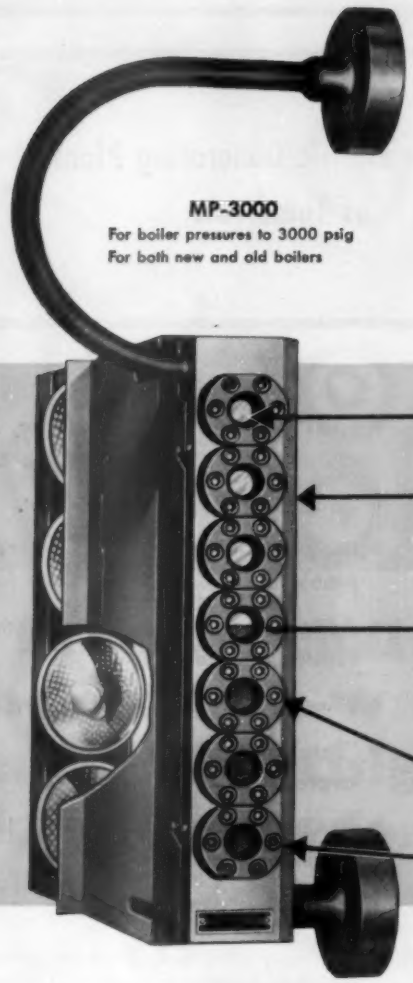
MORE THAN 950 DIAMOND MULTI-PORT GAUGES

In use and on order for over 240 Central Station Generating Plants



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For boiler pressures to 3000 psig
For both new and old boilers

SMALL ROUND PORTS INSTEAD OF LONG GLASS AND MICA STRIPS

GAUGE NEVER REMOVED FROM BOILER FOR GASKET CHANGES OR OTHER NORMAL MAINTENANCE

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WATER SHOWS GREEN

COMPLETE PORT CHANGE REQUIRES ONLY ABOUT 15 MINUTES

EACH PORT THERMALLY INDEPENDENT

Because the Diamond Multi-Port solves the problems inherent in water level gauges on boilers operating at high temperatures and pressures, it has had rapid and wide acceptance. In addition to the 950 for central station generating plants, more than 100 have been sold to industrial power plants.

Advantages of the Multi-Port are many. In addition to those shown above, it has maximum thermal stability for rapid starting . . . "Hi-Lite" illuminator for improved readability . . . welded construction for permanent tightness . . . end stems can be furnished instead of flanges . . . startling reductions in maintenance costs.

Write for Bulletin 1174V for more information.

7625

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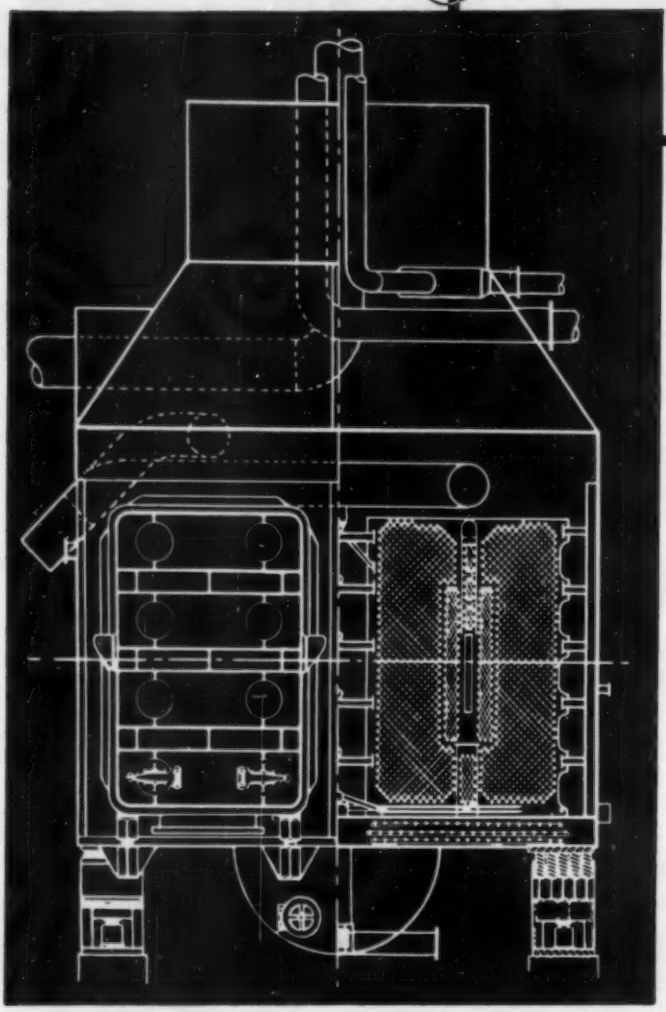
DUAL BANK Condensers

by C. H. Wheeler

For Your Electric Generating Plants of Tomorrow



- Specifically designed for larger, more efficient electric generating stations.
- Adaptable to your station layout.
- Designed to minimize field erection problems.
- Additional steam lanes shorten path and resistance to steam travel.
- Lower pressure drop and higher vacuum.
- "Zero" condensate temperature depression.
- DEAERATION . . . 0.01 cc per liter is attainable.
- Purity of condensate.

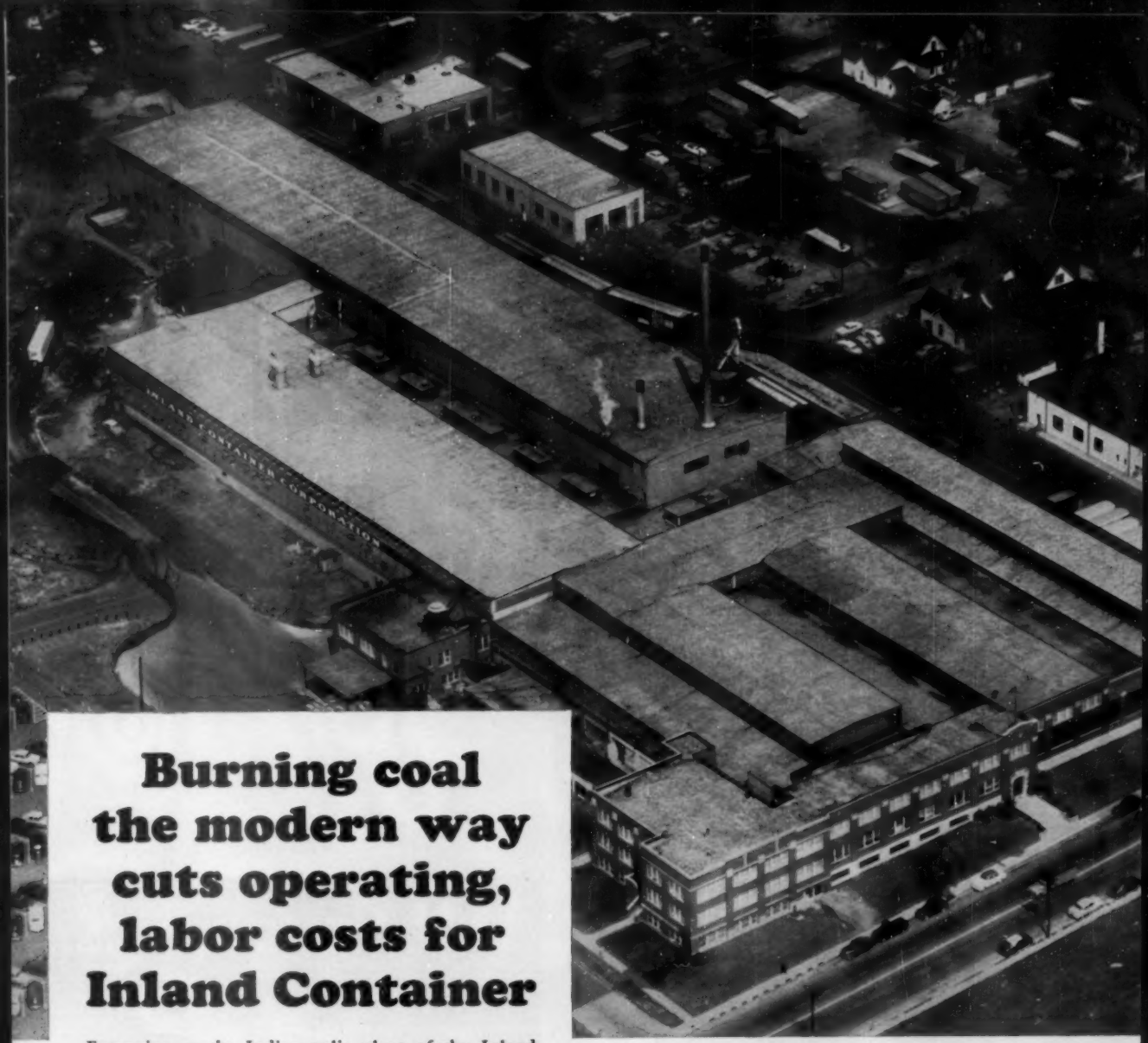
At C. H. Wheeler the most modern engineering techniques are at your service. Let our engineers help you. Contact your local representative or

C. H. WHEELER MANUFACTURING CO., 19th & LEHIGH, PHILADELPHIA 32, PA.

Manufacturers also of Vacuum Equipment • Pumps for Circulating Water, Condensate, Water Supply and Drainage Marine Auxiliary Machinery • Special Products for Atomic Service

WE 607

C.H. Wheeler OF PHILADELPHIA



Burning coal the modern way cuts operating, labor costs for Inland Container

Expansion at the Indianapolis plant of the Inland Container Corporation required additional steam capacity. The expansion was complicated by the limited space available. Inland's Engineering Department, with the assistance of W. J. Barrows & Associates, Engineering Consultants, solved the expansion problem.

Today the power plant has a new 30,000 lb.-per-hr. boiler and also a 300-ton silo. Liberal use has been made of automatic controls; coal and ash handling have been completely mechanized. Now steam loads are adequately maintained. Boiler room performance has been highly satisfactory and economical. Furthermore, this modernization has enabled Inland Container to effect considerable savings by more efficient operation of its power system.

For further information or additional case histories showing how other plants have saved money burning coal, write to the address below.

NATIONAL COAL ASSOCIATION
Southern Building • Washington 5, D. C.

Consult an engineering firm

Designing and building hundreds of heating and power installations a year, qualified engineering firms can bring you the latest knowledge of fuel costs and equipment. If you are planning the construction of new heating or power facilities—or the remodeling of an existing installation—one of these concerns will work closely with your own engineering department to effect substantial savings not only in efficiency but in fuel economy over the years.

facts you should know about coal

In most industrial areas, bituminous coal is the lowest-cost fuel available • Up-to-date coal burning equipment can give you 10% to 40% more steam per dollar • Automatic coal and ash handling systems can cut your labor cost to a minimum. Coal is the safest fuel to store and use • No smoke or dust problems when coal is burned with modern equipment • Between America's vast coal reserves and mechanized coal production methods, you can count on coal being plentiful and its price remaining stable.

First
Research-Cottrell
"Double-Deck"
Fly Ash Precipitator

Space was a big problem in this installation at the Burlington Generating Station of Public Service Electric and Gas Company of New Jersey. Two integral combination mechanical-electrical precipitators, large enough to handle 600,000 cfm of gas from Boiler No. 7, had to be squeezed into the smallest possible ground area.

If a conventional side-by-side arrangement had been used, these two units would have required about 1,700 square feet. By "stacking" the two combination precipitators, one on top of the other, Research was able to cut this space requirement by 50% — a saving of 850 square feet.

Although this arrangement had never been attempted with Research fly ash precipitators, Research knew from their experience with more than 500 central station Cottrells that it could be done. Guaranteed for 97% collection efficiency, these Burlington Generating Station units were placed in operation in October, 1955.

Perhaps you, too, have a knotty problem that demands a more creative approach — backed up by experience with over 500 fly ash precipitators. Whether you require a straight precipitator or a combination unit, at Research-Cottrell you can be sure of the most economical solution to your problem.

Other Research-Cottrell Precipitators at Public Service Electric and Gas Company of New Jersey

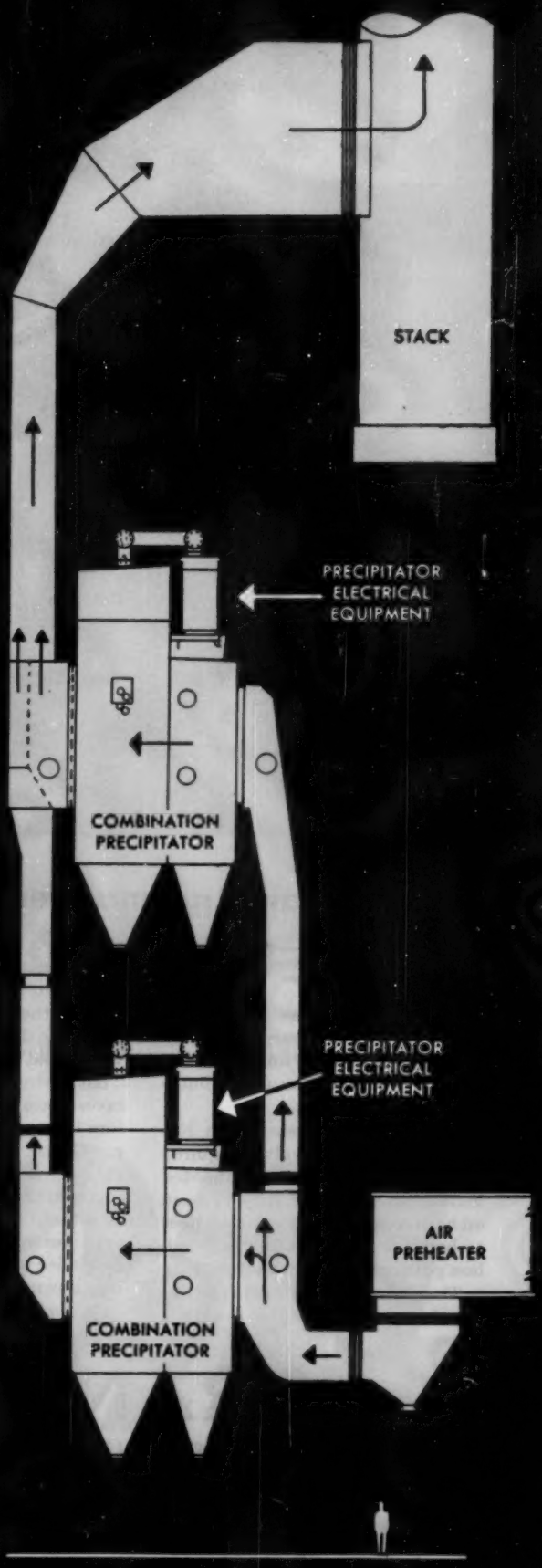
Installation Date	Generating Station	Boiler Number	Number of Pptrs.	C. F. M.
1937	Burlington	11	1	270,000
1938	Essex (Newark)	25 and 26	4	520,000
1940	Burlington	12 and 13	2	448,000
1941	Marion (Jersey City)	51 and 52	2	448,000
1942	Burlington	14 and 15	2	448,000
1946	Kearny	1 (Mercury Blr.)	1	160,000
1947	Essex (Newark)	1	3	380,000
1955	Burlington	7	2*	600,000
		Total	17	3,274,000

* "Double-Deck" Arrangement

Research-Cottrell, Inc.

Main Office and Plant: Bound Brook, New Jersey • 405 Lexington Ave., New York 17, N. Y.
Grant Building, Pittsburgh 19, Penna., 228 No. La Salle St., Chicago 1, Ill. • 111 Sutter Bldg., San Francisco 4, Cal.

Research-Cottrell's "double-deck" combination precipitators installed at Burlington Generating Station of Public Service Electric and Gas Company of New Jersey. At right, the simplified drawing shows the arrangement of the two integral mechanical-electrical collectors.



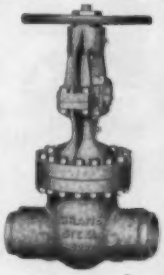
No repairs, no maintenance for these Crane valves —after 12 years on feed-water service

The day these Crane steel valves were installed 12 years ago, they started saving money for the Neches Butane Products Company's butadiene plant in Texas.

Not once have these 8-inch No. 76½ XR steel gate valves required repairs—not once have they needed maintenance . . . and they've been on hard, continuous service on lines to boiler feed pumps in this 3 million pound-per-hour steam plant.

There's more than meets the eye to valve service like this. From the outside, the average person wouldn't know the difference between Crane valves and others of the same type. That's why those who know valves investigate the *inside* quality before they specify. When the valves are Crane, they don't have to look far to find this quality—quality in materials, engineering and construction that literally means the difference between long, cost-free performance and expensive, aggravating, down-time maintenance.

Don't take chances with your all-important valves. Specify Crane, and make *sure* of getting service you can depend on—with the world's most complete line to select from, backed by a century of unparalleled experience in serving industry.



Get full information from your local Crane Representative, or write to address below.

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PIPE • KITCHENS • PLUMBING • HEATING

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BOOM LOADING "GENTLES" THE COAL INTO WAITING CARS . . .
MAINTAINS INITIAL SIZING AND BANS DEGRADATION

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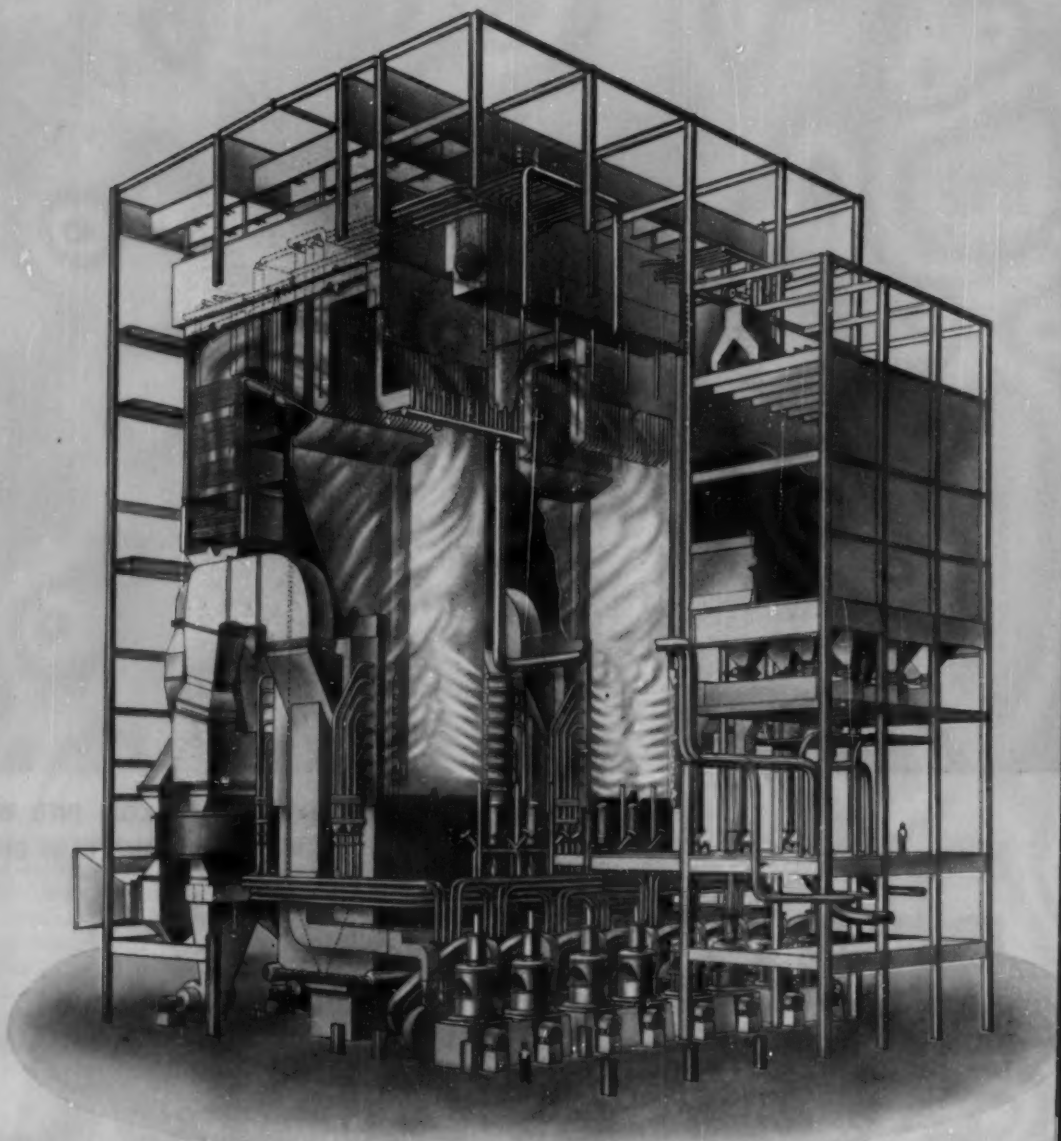
For New England: New England Coal & Coke Co., For Export: Castner, Curran & Bullitt, Inc.

A PROVEN DESIGN FOR

It's C-E's Controlled Circulation Twin-Furnace



THE C-E CONTROLLED CIRCULATION TWIN-FURNACE BOILER

Presently there are 35 such units in service, under construction or on order. They range in size from 200 to 325 mw with design pressures from 2050 to 2750 psi. The first unit went into service in November, 1954. At present there are eleven units on the line.

BETTER BIG BOILERS

Boiler with Tilting Tangential Burners

EVER-BIGGER TURBINES ARE THE ORDER OF THE DAY...

What this means to boiler design is obvious. Boiler circulation . . . superheat control . . . reheat control . . . expansion . . . structural size and design . . . the relationship of furnace volume and geometry to heat absorption surface. . . . accessibility . . . all are factors that caused C-E engineers to take a new, long, hard look at big boiler design. The result is the C-E Controlled Circulation Twin-Furnace Boiler with Tilting Tangential Burners. Here are some of its advantages.

1. The principle of controlled circulation guarantees positive water supply to all boiler parts in both furnaces in exact accordance with their needs.
2. Superheater and reheater surfaces are in separate furnaces — each fired by tilting tangential burners. Regardless of load, superheat and reheat temperatures can be controlled independently and accurately.
3. The superheater furnace can be lit off independent of the reheat furnace and heated water can be circulated through both to establish equal expansion throughout.
4. The reheat furnace can be lit off after the turbine is rolling and after steam is flowing through it. Thus protection of reheater surface during start-ups is assured.
5. The volume of each furnace can be properly proportioned to the heating surface it contains without the use of internal dividing walls. All walls are accessible for cleaning.
6. Lighter structural members can be used since load concentrations and spans are considerably reduced using two smaller furnaces in place of one extremely large one.

The facts itemized above tell only part of the story. For instance, C-E Controlled Circulation Boilers offer greater design flexibility, faster load response, steadier water level, shorter outages for maintenance, quicker start-ups and numerous other advantages. The C-E Tilting Tangential Burner exerts tight control over superheat and reheat temperatures and minimizes the use of spray water for desuperheating.

In all, Controlled Circulation *plus* Twin Furnace Design *plus* Tilting Tangential Burners add up to the right answer for big boiler design.

COMBUSTION ENGINEERING

Combustion Engineering Building • 200 Madison Avenue, New York 16, N. Y.

B-954

STEAM GENERATING UNITS • NUCLEAR REACTORS • PAPER MILL EQUIPMENT • PULVERIZERS • FLASH DRYING SYSTEMS • PRESSURE VESSELS • HOME HEATING AND COOLING UNITS • DOMESTIC WATER HEATERS • SOIL PIPE

TESTING and INSPECTION at Pittsburgh Piping

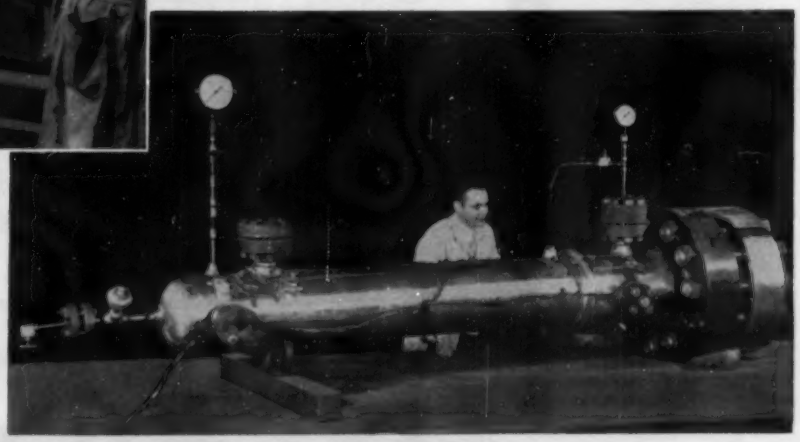
Fluorescent-penetrant examination detects surface defects. Pipe exterior is painted with fluorescent-fluid, then dusted with powder which draws fluid to surface where it is observed under ultra-violet light.

another
P. P. & E. service
which contributes to
Improved
HIGH-TEMPERATURE
HIGH-PRESSURE
PIPING

Fabricated chrome-moly header for central station piping system.

Close quality control is maintained throughout the fabricating process at Pittsburgh Piping by means of almost a score of different types of tests and examinations — three of which are shown on this page. Our technical staff supervises these procedures — checks all materials and production operations. This activity assures that each component, assembly, and the final piping system fabricated and erected by Pittsburgh Piping meets code and insurance requirements . . . fills the customer's specifications . . . and gives trouble-free service.

This testing instrument transmits ultra-sonic waves into pipe wall, with their movement around the pipe being indicated as a consistent pattern on the instrument's screen. Any internal defect in the pipe wall reflects the waves back to the instrument more quickly and is thereby revealed on the screen.



Hydrostatic testing at Pittsburgh Piping. This stainless steel surge tank is being tested at pressure up to 5,600 psi. Strain gauges are used to check closely for plastic deformation.

PRODUCTS AND SERVICES

Carbon Steel Piping	Forged Piping Materials
Cast Iron Fittings	Headers
Cast Steel Fittings	Manifolds
Chrome-Moly Piping	Pipe Bends
Copper Piping	Stainless Steel Piping
Corrugated Piping	Van Stoning
Creased Bends	Welded Assemblies
Expansion Bends	Welded Stainless Steel Tubing
Flanges	Welding Fittings

Pittsburgh Piping
AND EQUIPMENT COMPANY
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CANADA: CANADIAN PITTSBURGH PIPING, LTD.
835 BEACH ROAD—HAMILTON, ONTARIO

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PP-23

24"

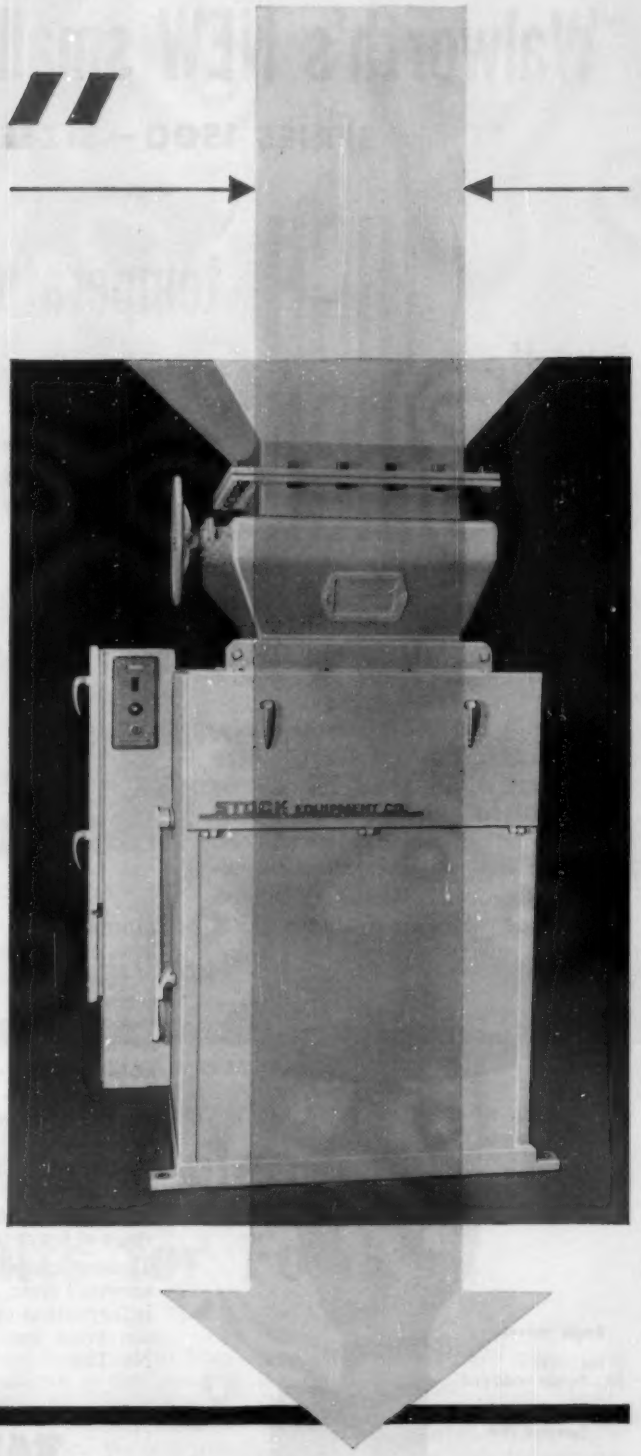
STRAIGHT THROUGH

No Restrictions...
No Baffles...
No Sloping Skirts

The *new* **S-E-Co. Model 50 Coal Scale** has been designed to eliminate coal stoppage difficulties. This scale makes it possible for you to get maximum accuracy of weight of coal burned for boiler tests, to keep inventory records, and to balance mills without danger of coal plugging and hanging up.

The inlet of the Model 50 is 24" inside square — the vertical feeder skirts carry a 24" stream of coal — and the stainless steel weigh hopper has a 24" wide outlet.

In addition, the large, rigid and well gasketed doors of the Model 50 maintain a clean installation that is easy to service. Roller bearings on the weigh hopper gate and other carefully worked out improvements make this scale of tomorrow the scale for you today.



SPECIALISTS IN
BUNKER TO PULVERIZER AND
BUNKER TO STOKER EQUIPMENT

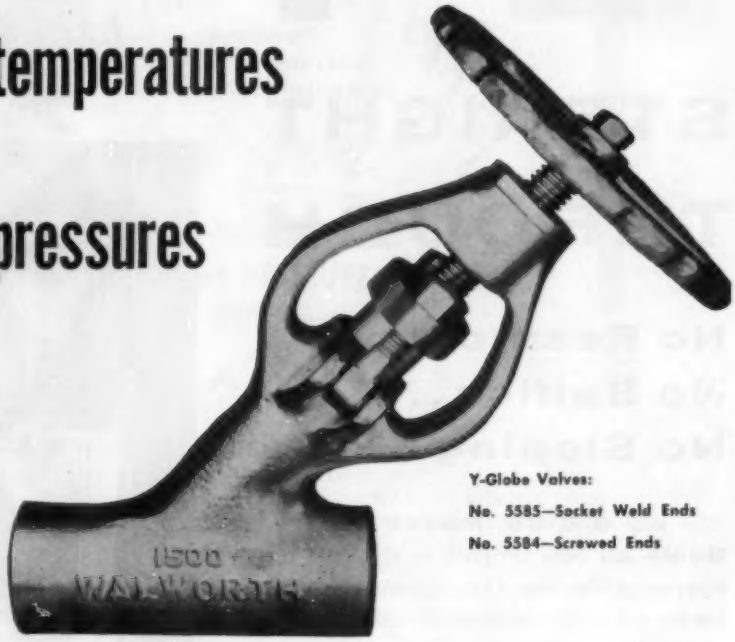
STOCK Equipment Company

745-C HANNA BLDG., CLEVELAND 15, OHIO

Walworth's NEW small cast steel valves

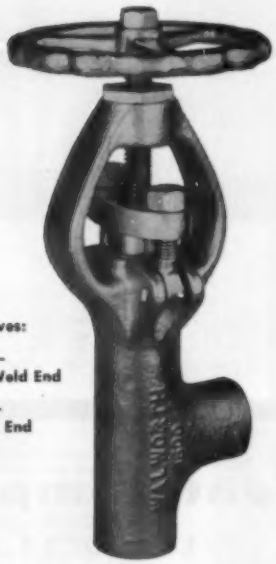
SERIES 1500 — SIZES ¼ to 2 inches

handle HIGH temperatures
HIGH pressures



Y-Globe Valves:
No. 5585—Socket Weld Ends
No. 5584—Screwed Ends

Walworth is proud to make these new Small Cast Steel Valves available to power stations . . . oil refineries . . . ships . . . wherever piping is subject to severe pressures and temperatures. Non-shock service ratings of these valves: 1500 psi–950F for steam; 3600 psi–100F for water, oil or gas. Cast of chromium molybdenum steel, they are compact and light, yet exceptionally strong. Both Y-Globe and Angle type valves are available.



Angle Valves:
No. 5587—
Socket Weld End
No. 5586—
Screwed End

Simplified Walworth design eliminates many of the valve problems encountered in high pressure service. Among the features of this new valve are:

INTEGRAL BODY AND YOKE — made from a single casting without threading or welding. Bonnet joint — always a potential source of leakage — is eliminated. Valves can be reassembled quickly and easily.

ROTATING DISC — prevents valve seat distortion and consequent leakage. Cuts down replacements.

WELDED SEAT RING — compensates for changes in pressure and temperature—eliminates a major source of leakage.

SPECIAL BACK SEAT BUSHING — permits repacking the valve under pressure with greater safety.

PACKING CHAMBER — designed to dissipate heat thus keeping packing rings at lower temperatures—gives them longer life.

These valves are available with either socket weld ends or screwed ends, in sizes ranging from ¼ to 2 inches. For further information on Walworth series 1500 Small Cast Steel Valves, see your local Walworth distributor, or write for Circular No. 134.

WALWORTH

valves • fittings • pipe wrenches

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DISTRIBUTORS IN PRINCIPAL CENTERS THROUGHOUT THE WORLD

CHEMICAL CLEANING AT THE FORD MOTOR COMPANY, RIVER ROUGE, MICHIGAN

Dowell chemical cleaning gets results for Ford

When you have men and costly equipment in your care you don't take chances. That applies to chemical cleaning, too.

You—like Ford—want the company and the men who do your chemical cleaning to fulfill certain requirements. They must be as safety conscious as you are. This has to be your number one requirement.

Next, you want these men to have extensive experience so that you get the best possible job. And you want them to be backed by research facilities, because you know the best possible job can be done only when the latest developments are employed.

These requirements are basic with Dowell, as thousands of companies throughout the country can testify.

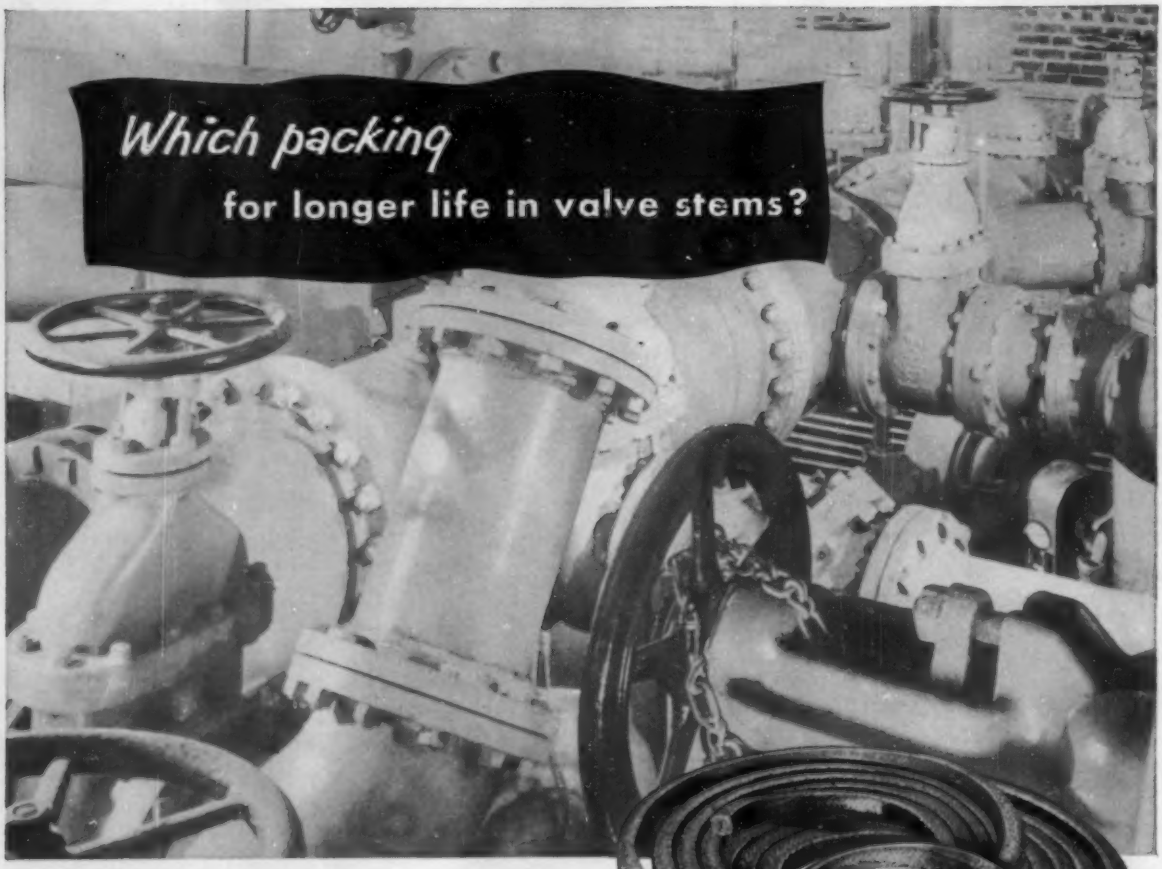
You get them and many more when you have Dowell do your chemical cleaning.

Don't take chances. Have your chemical cleaning done by experts. When you want maximum safety and efficiency backed by research in your chemical cleaning—call Dowell. Or write Dowell Incorporated, Tulsa 1, Oklahoma, Dept. J-25.

chemical cleaning service for industry

DOWELL

A SERVICE SUBSIDIARY OF THE DOW CHEMICAL COMPANY



. . . for heavy fluids, steam, water and gas . . . *it's J-M Jewett®*

Strong, tough Jewett has been proven the ideal packing for heavy duty valve stem service against crude and heavy oils, tar, molasses and other heavy gummy fluids. It also provides efficient sealing against steam; fresh or salt, hot or cold water; air; gas and some chemicals requiring a packing free from rubber.

The basis of Jewett's exceptional durability is its construction of high-quality long fibre asbestos yarn with fine copper wire inserts. This yarn is braided over a lead ribbon core and formed square. Style 10 is treated with a heavy bodied, heat-resisting lubricant which won't bleed in valve stem service. Furnished graphited in coil or ring form in sizes from ⅛″ up.

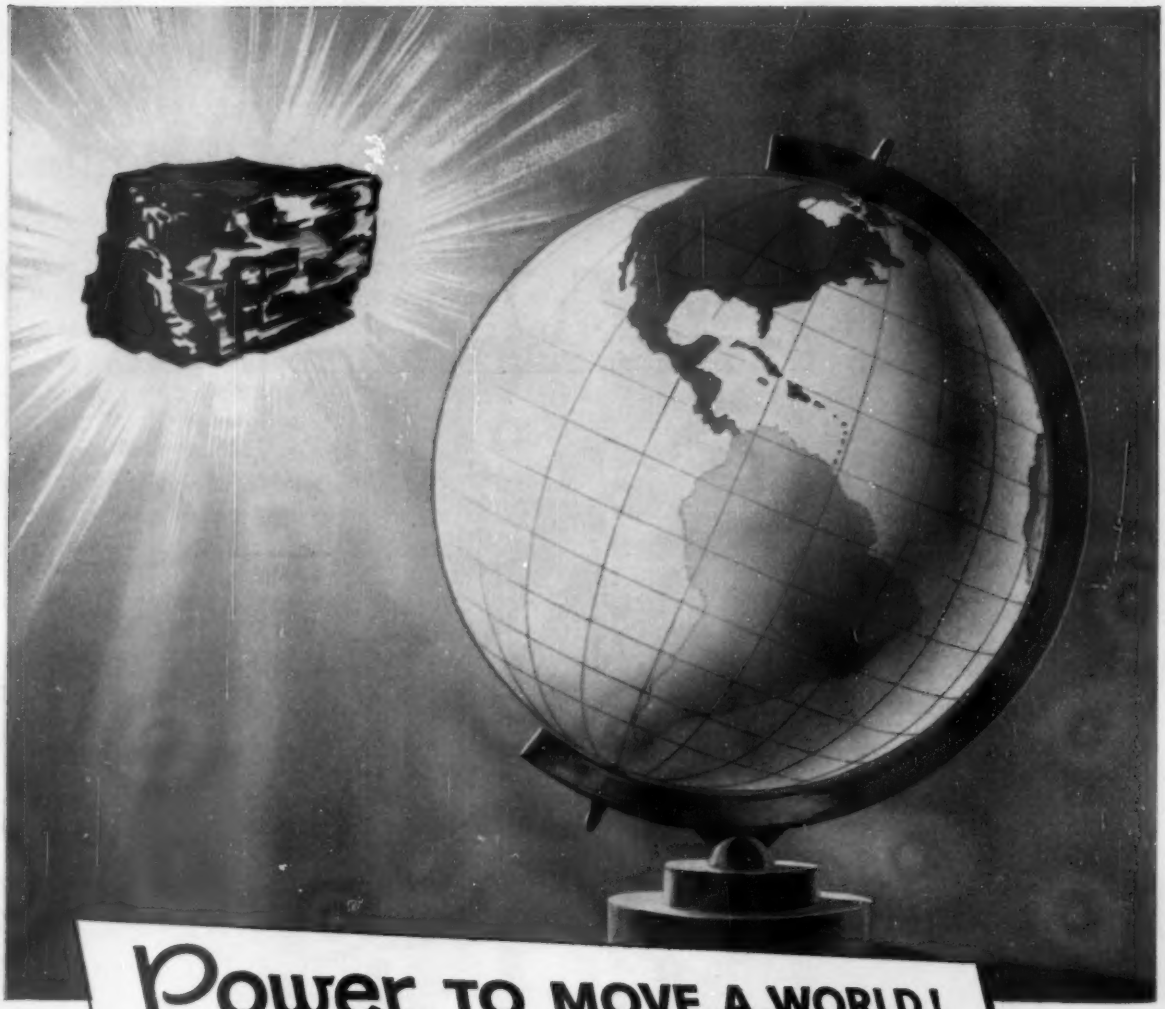
. . . for superheated steam and gases to 900F *it's J-M High Temperature*

When valves are operating in high temperature service, your best packing choice is Johns-Manville High Temperature Style 398. It retains its resilience, holds a tight, lasting seal against superheated steam and dry gases under elevated pressures and temperatures up to 900F.

To obtain this high sealing efficiency, Johns-Manville braids asbestos yarn of high purity over a plastic core of special heat resistant composition. For extra strength, the yarn is reinforced with tough heat and corrosion resistant Monel wire. The packing is formed square and then lubricated with mica. Furnished in ring, coil and spiral form in sizes ¼″ to 1″.

Your local J-M distributor carries full stocks of Jewett, High Temperature and other packings. Call him today or write Johns-Manville, Box 14, New York 16, New York. In Canada, Port Credit, Ontario.

Johns-Manville PACKINGS, GASKETS and TEXTILES



Power TO MOVE A WORLD!

➔ America stands on the threshold of a golden age. The sinews of her dynamic economy are flexed as never before. Increased power for untold requirements will be needed . . . and *met* by the most dependable supply of low-cost energy—*Bituminous coal!*

Proven usable reserves in B&O territory contain billions of tons—*available for centuries to come.*

CONTACT OUR COAL TRAFFIC REPRESENTATIVES!
You'll receive details on the most efficient, low-cost Bituminous coal for your particular requirements—
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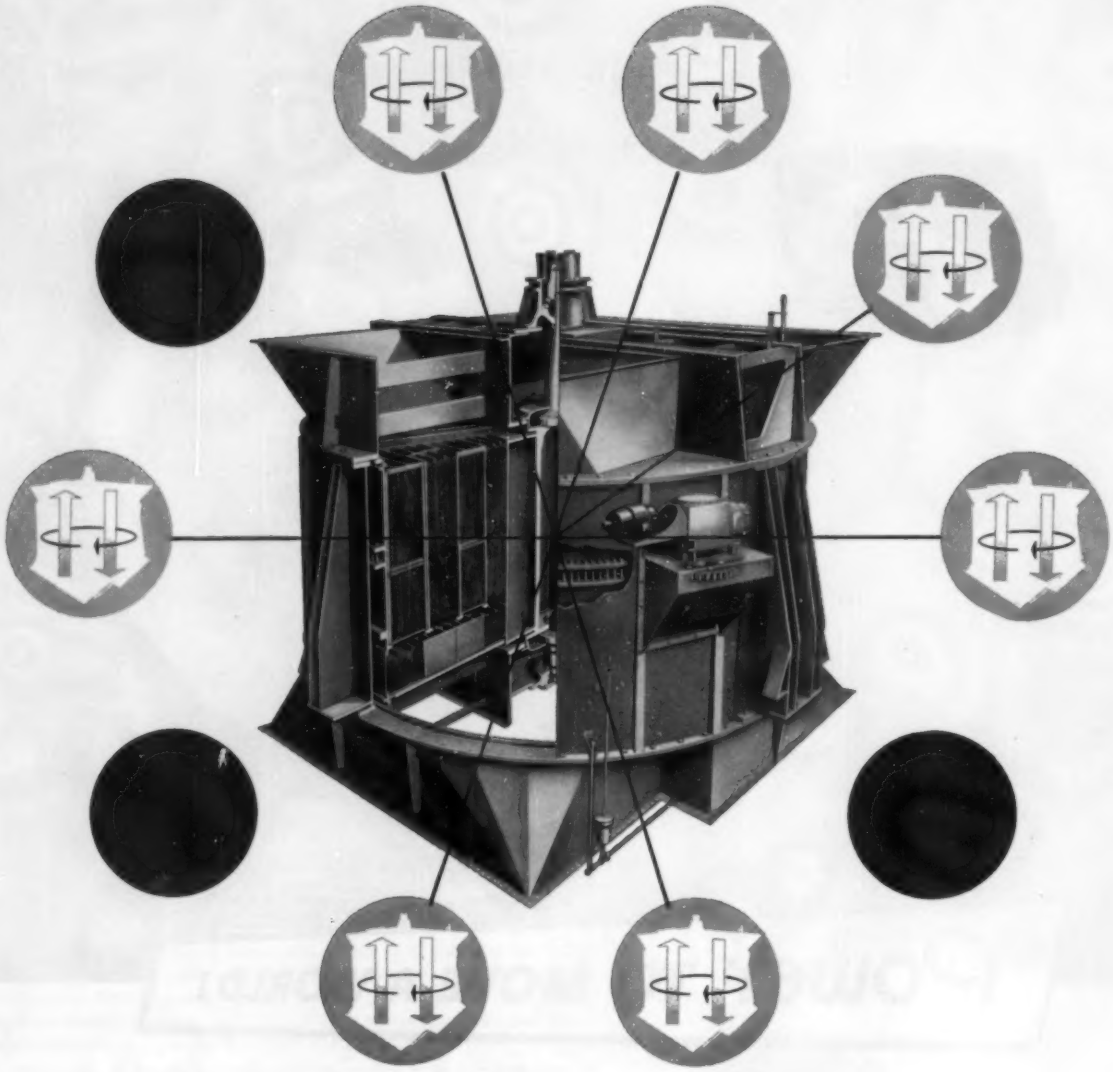


7 out of 10 *air preheater installations are Ljungstrom®*

Advantages of the Ljungstrom Air Preheater

- Size for size, recovers more heat than any other type.
- Reduces fuel consumption. Permits use of lower-grade fuels. Increases boiler output and reliability.
- Eliminates cold spots . . . keeps corrosion to a minimum.
- Easier, faster to clean and maintain.
- Requires far less supporting steel and is quickly erected.

FUEL ECONOMY is the big reason. Size for size, the Ljungstrom recovers more heat than any other type of air preheater. And with every 45-50 F of air preheat you cut your fuel bill 1%.

Write now for your copy of our 38-page manual, for handy reference.

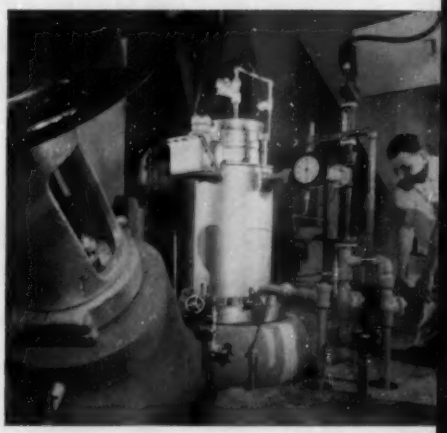
The Air Preheater Corporation 60 East 42nd Street, New York 17, N. Y.

Westinghouse "canned" pump eliminates leakage at VEPCO

Zero leakage! No injection water sealing required. Pump may be kept on hot or cold stand-by. No seal maintenance. Windings protected by nickel "cans" welded in place. No bearing lubrication.

These are advantages realized by Virginia Electric Power Company with the installation of a Westinghouse "canned" motor pump in the controlled circulation boiler system of the new Possum Point Station.

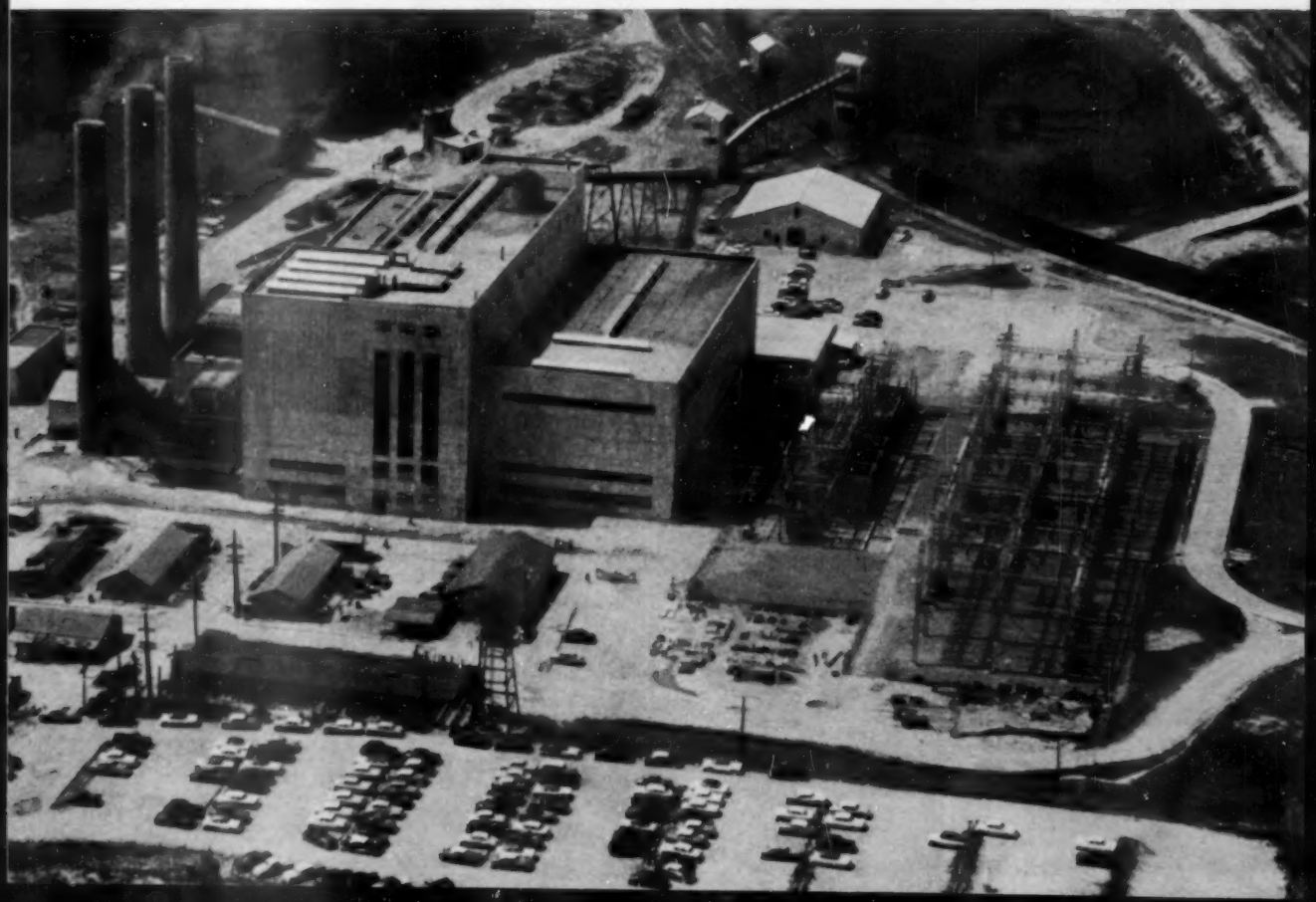
VEPCO, Stone & Webster and Combustion Engineering pioneered the power station application of this pump which was first developed to handle radioactive fluids in nuclear reactor loops. All the development work is now complete and the installation has been in actual service at Possum Point for over a year. J-57005



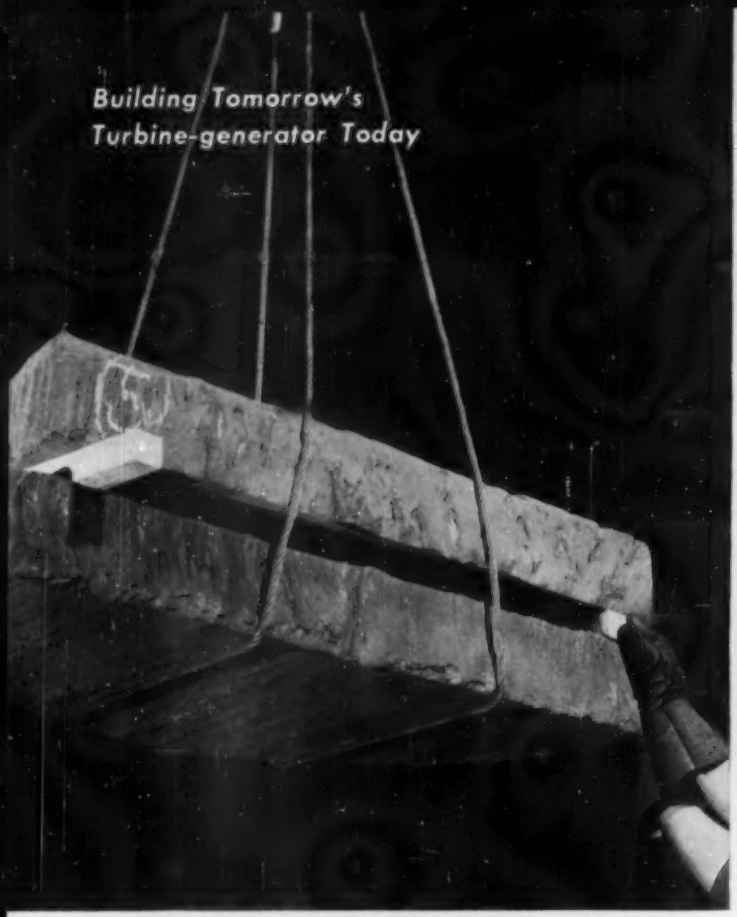
Westinghouse "canned" pump in Combustion Engineering controlled circulation boiler at Virginia Electric's Possum Point Station.

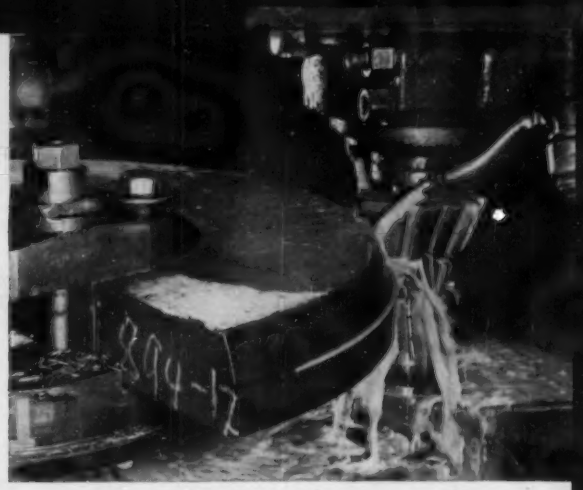
WATCH WESTINGHOUSE!

COVER THE PRESIDENTIAL CAMPAIGN ON CBS TELEVISION AND RADIO!



Building Tomorrow's
Turbine-generator Today





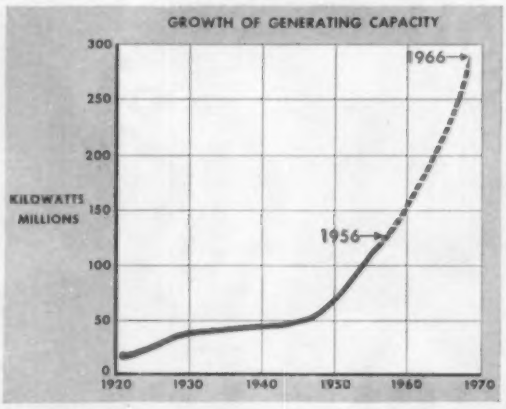
THE HIGH-PRESSURE END DIAPHRAGM WEBS are made from heavy alloy steel plates or castings. Some are ten inches thick and can withstand high pressure drops and maintain close clearances.

THE WEB is then carefully machined for welding (top). Nozzle partitions are machined from solid chrome-iron alloy and assembled in punched bands (bottom).

How General Electric builds sturdy nozzle-

TO MEET TOMORROW'S EXPANDING LOADS

GENERAL ELECTRIC MAINTAINS a continuing program of research on turbine diaphragms. This smoke tunnel provides a visual indication of how steam flow will follow new nozzle designs.



G.E. works with electric utilities and consulting engineers in these vital turbine-generator areas:

BASIC RESEARCH

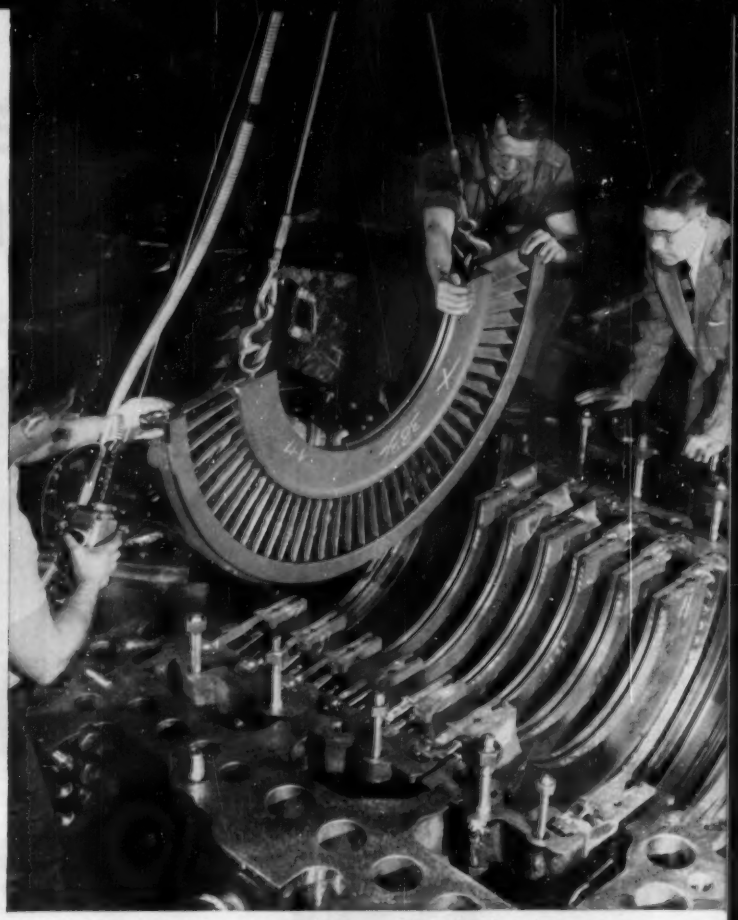
APPLIED RESEARCH

PRODUCT DEVELOPMENT: NOZZLE-DIAPHRAGMS

TESTING

MAINTENANCE

THIS NOZZLE assembly is welded to the web and outer ring (top). A finishing operation puts a high polish on the partitions for a smooth steam path (bottom).



DIAPHRAGM HALVES are lowered into the turbine shell. The rotor is then assembled and the upper shell containing the top half of the diaphragm is added to form a series of complete compartments.

diaphragms to reduce turbine maintenance

TOUGH CONSTRUCTION HELPS PROTECT STEAM PATH AGAINST DESTRUCTIVE FOREIGN MATERIALS

Internal damage to the steam path can be a costly and time consuming cause of turbine shutdown. Should large amounts of foreign material enter the steam path whole rows of buckets and partitions might be severely damaged. This could mean a long and costly outage.

TO HELP GUARD against a long outage, General Electric builds turbine nozzle-diaphragms of tough, sturdy construction. And here's how they help. Should foreign materials enter the steam path, these rugged nozzle-diaphragms "compartmentalize" damage to a small area. This greatly simplifies bucket repairs or replacement.

GENERAL ELECTRIC MANUFACTURES these diaphragms from solid castings or plates carefully machined to shape. Nozzle partitions are machined from solid chrome-iron alloy and welded to, or cast integral with, the webs. These partitions must direct the steam flow at the proper angle and velocity to the adjacent buckets.

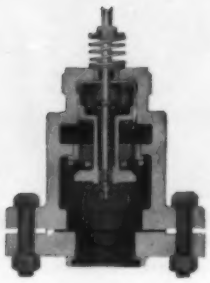
In this and many other areas of research G.E. is working with electric utilities and consulting engineering firms to design the power makers for tomorrow's load growth. For more information on General Electric turbines write for GER-905, Large Steam Turbine-Generator Department, General Electric Company, Schenectady 5, N. Y. 234-40

Progress Is Our Most Important Product

GENERAL ELECTRIC

BAYER
STEPS UP BOILER PERFORMANCE

DISTINCTLY DIFFERENT



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WITH THE Bayer Balanced Valve Soot Cleaner the balancing chamber above the piston disc impounds steam when the valve closes, thus relieving valve parts from shock. The valves remain *steam tight* because the dashpot action causes the valve to seat gently. Unbalanced valves close with a hammer stroke and soon become leaky.

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Hall Industrial Water Report

VOLUME 4 OCTOBER 1956 NUMBER 5

Industrial Water, Pollution of Streams, Water Shortages—These are Serious Problems Confronting Industrial Areas Everywhere

Treating water for re-use, eliminating contaminants from streams, and engineering water in short supply are functions of chemical engineers skilled in water technology. Hall Laboratories is providing these services for industry at home and abroad.

England Was Not Merry England

Things were not so jolly for a large English factory when plans for expansion ran head-on into the fact that not enough suitable water was available for an enlarged power plant and increased process facilities.

The plant had two main water supplies. First-quality water from the city mains was limited in amount because of existing industrial and residential needs. The other supply was contaminated with sea water, decayed vegetation, sewage and synthetic detergents.

Hall Laboratories was engaged to conduct a plant-wide survey to assess all uses of water in the plant and to recommend means for reducing water consumption, improving and extending the use of the inferior quality water, and making condensate, treated and untreated water available for re-use. The primary concerns of Hall staff engineers H. A. Reda and Leonard Highley, Jr., were to limit use of the first-quality water so as to release a sufficient amount for the new high-pressure boilers, and to develop a better grade of process water.

The plant was using two million gallons of first-quality water and two million gallons of process water per day. Working from point to point through the plant with the cooperation of the plant staff, Highley and Reda were able to recommend a number of water saving changes. For example, about 150 drinking fountains were allowed to run constantly to keep the water cool. All this waste could be avoided with automatic coolers. Furthermore, it was concluded that city water was not required for cooling and process work and that an acceptable grade of process water, better than the second existing supply, could be provided by treatment of the effluent from a neighboring sewage disposal plant. Using this same treated water the plant could install a number of closed cooling systems, reducing requirements for cooling water by 90 percent.

Reda and Highley estimated that the conservation program will reduce the daily requirements for city water and for the new process water to one million gallons of each per day. The plant can now proceed with its plans for expansion. In addition, it is expected that the savings in water costs will pay off the investment for the changes in 4 to 5 years.

Water Tax Increased By Contaminated Effluent

When a steel products manufacturing plant near Cincinnati, Ohio, received a water tax bill more than 12 times the usual amount, they learned to their chagrin that their plant was contaminating an adjacent creek as well as discharging contaminated water to the city sanitary sewage system.

Work was started at once to eliminate the pollution. Some effective inplant changes were made, but these were not enough, since a subsequent analysis of the plant's effluent by the authorities revealed more suspended solids than tolerable in the cooling water being discharged to the creek.

A factual survey by J. H. Covode of Hall's Cincinnati office and H. A. Reda of the Pittsburgh staff established that suspended solids in the water from the plant's once-through cooling system were the only objectionable contaminant. As a result, part of these solids, originating from the dust collectors, were diverted temporarily to the municipal sanitary sewage system. When Reda and Covode pointed out that the water from the dust collectors could be clarified, studies were undertaken to compare the cost of doing this with the saving that would be realized from reduction of taxes for discharge of unpolluted water to the city sewage system.

Further study revealed that approximately 50 percent of the suspended solids carried by the cooling water came from precipitation of dissolved iron originating in the plant well water. Less but significant contamination occurred in the following ways. At the end of a melt, when the furnaces were tilted, cooling water was discharged directly to the dust-laden floor and into the open floor drains. This water then flowed into an open ditch located alongside the building. Roof drains also discharged into this ditch. The water then ran under a railroad culvert where dirt was shaken into it when trains passed overhead.

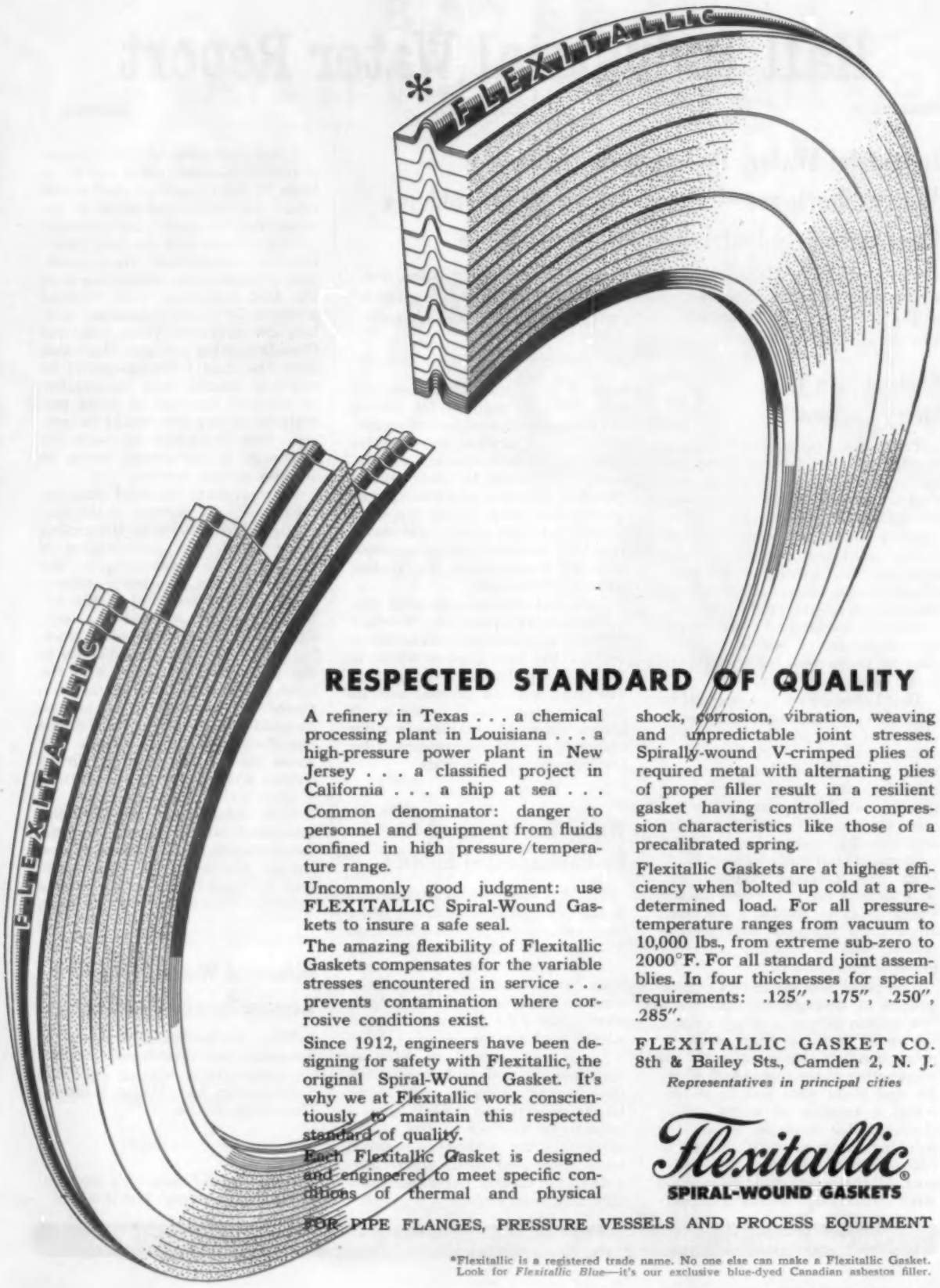
After plant management had put into effect all corrective changes, the authorities were satisfied and the tax was dropped to the normal rate for unpolluted water with a saving of more than $6000 per year.

Industrial Water Problems Require Special Handling

There are no "stock answers" to industrial water problems. For information write, wire or call Hall Laboratories, Inc., Hagan Building, Pittsburgh 30, Pa.

Water is your industry's most important raw material. Use it wisely.

Hall Laboratories, Inc.—Consultants on Procurement, Treatment, Use and Disposal of Industrial Water



RESPECTED STANDARD OF QUALITY

A refinery in Texas . . . a chemical processing plant in Louisiana . . . a high-pressure power plant in New Jersey . . . a classified project in California . . . a ship at sea . . .

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Editorial

Tackling the Fly-ash Problem

The handling and disposal of the waste products from today's power boilers constitute a problem of major proportions to the public utility industry. A number of attempts reaching back over a span of years have been made to find a market for fly ash and slag wastes and thereby render their collection and disposal a less burdensome problem. Recently our contemporary, *Electrical World*, staged a three-day conference in Pittsburgh in the hopes of initiating a concentrated campaign on the part of the utilities to market fly ash.

There are evidences that the times are propitious for a vigorous marketing program. The adoption by the ASTM of two tentative specifications involving fly ash in portland cement concrete is one such sign. This action plus the same body's acceptance of fly ash as a pozzolan in cement establishes this material as one possessing valuable and hence marketable properties. Experimental projects employing fly ash in concrete roadways and as a filler in bituminous paving compounds further testify to the suitability of fly ash in construction work. In the light of these developments the proposed federal highway construction program seems to offer an immediate market outlet for all fly ash the utility industry could conceivably furnish. Yet we feel the establishment of lasting markets for fly ash will continue to be an uphill fight.

We salute *Electrical World* and the utility industry's mutual recognition of these facts. We feel that out of this closing of the ranks, if such a closing does occur, will come the fundamental data vital to the development of permanent markets. Such fundamental data will not only identify the physical and chemical characteristics of fly ash from the more commonly used coals but what combination of characteristics prove best for what purposes. And going beyond, information of this nature may reveal what the anticipated coals of the future would produce in the way of fly ash and possibly aid in appraising available firing methods to best handle these coals in view of fly ash marketability. The perplexing question of how much preparation should be undertaken on coal at the mine level could conceivably enter into these studies. All in all we feel this pooling of interest in marketing fly ash could establish a precedent and lead to a method of attack upon other industry-wide technical problems that could accelerate progress.

One Way To Arouse Action

As we go to press the Atomic Industrial Forum of 1956 is just drawing to a close. This Forum which we will report upon in our next issue drew some 1000 registrants from our own and 25 foreign countries. The appeal of the Forum for this widespread audience was the usual one of an opportunity for an exchange of thoughts and a possible profit from the ideas of other people active in the development of atomic energy.

This Forum, following as closely as it did after the Geneva Atomic Energy Conference of 1955, suffered some from a dearth of truly new information. Yet this meeting in common with all such gatherings offers individual authors the chance to make public any real or imagined obstacles to advancement of the field of interest. It is always disappointing to see how rarely this chance is grasped. Fortunately one author saw fit to do so, however, and we applaud his frank comments on the reasons for the apparent lethargy in developing the techniques of chemical reprocessing of spent fuel elements.

The author, George F. Jenkins, manager, chemical processing, Union Carbide Nuclear Co., told his audience that the lack of interest in the profit requirement and its inseparable component, the Federal Income Tax, evident in the present assessments of costs for reprocessing fuel elements was a severe deterrent to arousing activity on the part of the chemical industry. The most authoritative and up-to-date source of cost estimates in the author's opinion, the Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy, more commonly known as "the McKinney Report," lists average charges for reprocessing that promise unattractive returns on investment, and further this Report pegs depreciation at $3^1/_2$ per cent which is felt to be too low for plants that are quite likely to be obsolete in a five-year period. As matters stand now the chemicals industry can find other new projects that carry more appeal for capital risk than that of reprocessing spent fuel elements.

Mr. Jenkins, in addition to urging another look at present assessments of costs, made certain recommendations for speeding the acquisition of knowledge in the one area that he holds promising for making reprocessing a profitable venture—the utilization of the fission products and radioactive energy from the spent fuel elements.

We salute Mr. Jenkins for his forthright statements of a situation that calls for remedy and his recommendations of suggested remedies. Certainly all interested in furthering atomic energy have been duly notified of a barrier in the path ahead and should investigate its seriousness and ways and means of removing it. If meetings such as the Forum are to continue their value as a gathering place for the various interests engaged in atomic energy developments, it will be due largely to papers similar to Mr. Jenkins' in which the difficulties as well as the progress of individual participants are made common knowledge.

This article, first of a series, considers the growth of boiler operating pressures and capacities and describes the design problems they pose for the pump manufacturer—problems which the author feels must be resolved or retard the progress of power plant design.

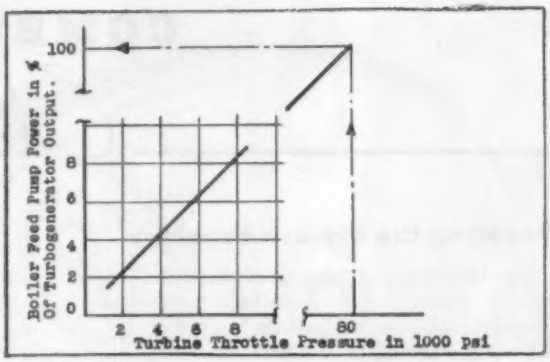

Fig. 1—Boiler feed pump power bids fair to be the tail that wags the dog for operating pressures

Steam Power Plant Trends and Their

By

I. J. KARASSIK*

Worthington Corp.

WERE it proper to present our subject-matter in a somewhat lighter vein than is normally the case for serious engineering reports, this group of articles could have been more aptly entitled "The Tail That Will Wag the Dog." The aptness of this suggested title will become readily apparent when consideration is given to the growing importance of the boiler feed pump in today's steam power plant. Some thirty years ago, when steam turbines operated at the modest pressure of 625 psi, the boiler feed pumps consumed a mere 0.5 per cent of the total plant output—certainly a very negligible proportion. At today's pressures of 2350 psi, the boiler feed pump share of the total plant capability has grown to 2.5 per cent. For a super-pressure plant operating at 3500 psi, the feed pump power requirements increase to 4 per cent and to 6 per cent for a 5500 psi steam pressure. Should we permit ourselves the whimsy of extending this relationship on up the pressure scale, we could arrive at the absurd conclusion that were the operating pressure to reach somewhere around 80,000 psi, the entire output of the turbo-generator would be required to drive the boiler feed pumps, leaving us not even the few kilowatts necessary to drive some of the other plant auxiliaries (see Fig. 1).

Long before we were to reach such a ridiculous situation, other factors would intervene to limit the operating pressure to a more reasonable value. Even the most optimistic and radically inclined prophets do not feel that operating pressures above 8000 or 10,000 psi will ever be reached. Much before our technological advances would permit exceeding these pressures, direct conversion of nuclear to electric energy will have relegated the steam power plant as we know it to the role of a museum exhibit. But it is obvious that the amount of power taken up by the boiler feed pump has become an important factor in the economic evaluation of steam cycles operating at higher pressures. In other words, when the reduction in the net power generated caused by an increase in operating pressure begins to approach the improvement in performance due to this increased pressure, the boiler feed pump itself becomes the limiting factor of the cycle.

What then can we say of the more immediate future of the boiler feed pump in the light of the trends and developments in steam power generation? Because we wish to limit our speculations to the next few years during which nuclear energy power production will comprise an almost negligible proportion of the total, the present report will limit itself to the field of power production in plants utilizing conventional fossil fuels.

Of necessity, we must approach our task from two separate angles. First we must consider trends and developments in steam power generation and examine their effect on the boiler feed pump. We must then consider various improvements possible in boiler feed pump design and application and the effect these can have on the power plant itself.

Growth of Operating Pressures

Power plant designers and power plant equipment manufacturers are constantly exercising their ingenuity in order to reduce the production cost of electric power. And, since the investment cost of the power plant itself is an important component of the overall production cost, a reduction in the plant net heat rate is equally important to a reduction in the cost of any new power plants.

The cost of fossil fuels has been mounting steadily. In order to combat the effect of this rise on the cost of

* Assistant to Vice-President and Consulting Engineer, Harrison Division

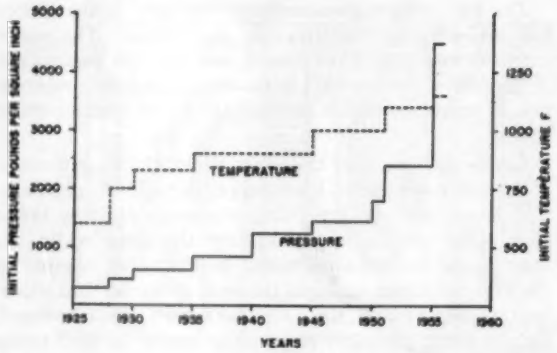

Fig. 2—Steady advance of operating pressures and temperatures over the years are pictured above

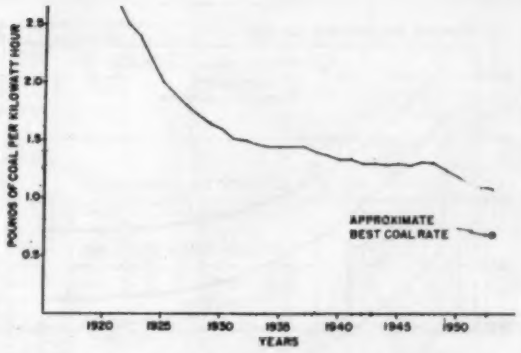

Fig. 3—Along with the advance in Fig. 2 the average coal consumption per kwhr has dropped off over the years

Effect on the Boiler Feed Pump.—I

power production, it has been necessary to improve materially the heat rate of new power plants. Up to now, the most effective means of accomplishing this has been an increase in operating steam pressure and temperature. Fig. 2 illustrates the changes in these two characteristics over the past thirty years. The result of these changes is illustrated on Fig. 3, which shows the average fuel consumption per kilowatt-hour over the same period. A more direct picture of the relationship between economy of power production and steam conditions is presented on Fig. 4 which shows the heat rate of steam power plants at various steam pressures and temperatures.

The first thought which comes to mind in examining Fig. 4 is that the improvement in heat rate—that is, in plant efficiency—appears to be reaching a point of diminishing returns. And while further increases in operating pressure can yield still lower heat rates, the question arises whether increased investment costs will not swallow up any further improvement in plant efficiency. In other words, have we reached the point where further improvements must be obtained by means other than increasing pressures and temperatures?

Before attempting to answer this highly controversial question, we must bring into focus still another factor which will have a bearing on the decision which will be made by a number of utilities in this regard. A very important contribution to the philosophy of steam power plant design has been made in the recent years by the operating personnel of these plants. This contribution consists of the introduction of a "relative maintenance and availability factor" concept into the evaluation of benefits to be derived from higher operating pressures and temperatures and from the more complex operating cycles which are necessary to obtain greater cycle efficiencies and lower plant heat rates.

It has been shown that the rate of improvement in cycle efficiency as a result of further increases in steam pressures and temperatures is steadily diminishing. At the same time, it is obvious that the complexity of these new cycles requires in many cases an increased personnel for normal operation and may also require a greater amount of maintenance. At least, this must remain true in the early stages of development, until such time that the experience factor both in the construction of the equipment and in its operation reduces these twin problems to the point where they are no more thorny than they are today for the more conventional, lower pressure power plant. In the meantime, therefore, it would appear that the majority of the utilities will charge some sort of a penalty against higher pressure and temperature plants in their evaluation. This penalty will reflect three sources of increased operating expense: (1) increase in operating personnel, where such is indicated, (2) increase in potential maintenance expense, and (3) decrease in availability and increase in cost of supplying replacement power from a less efficient power plant or from an adjoining utility.

It is true that the last two items represent an intangible cost, difficult to evaluate. At the same time, several utilities have already made some approximate assumptions and have even assigned tentative dollar values to these items. At least for the present, most utilities consider the extension of steam pressures and temperatures into the supercritical range a more or less experimental venture. Accordingly, they intend to bide their time until field experience of sufficient scope will have accumulated and will have eliminated this experimental characteristic from such installations.

These considerations should not lead us to the conclusion that we can disregard the growing trend to higher operating steam pressures. Instead, the fact that the number of power plants to operate in the upper pressure range will be somewhat limited in the near future, should lead pump designers to redouble their efforts in arriving at the most economical and reliable solution of the boiler feeding problem. Failure to solve this problem satisfactorily would result in retarding the progress of steam power plant design.

Once-Through Boilers

The announcement of the first few supercritical pressure power plants has spurred a great deal of interest

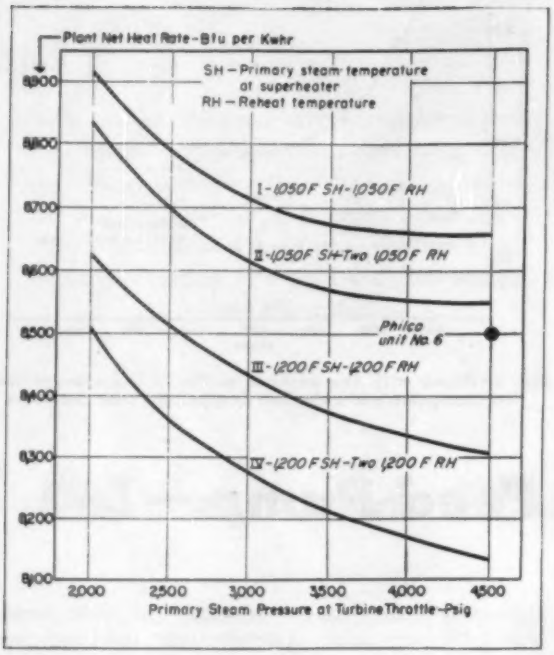

Fig. 4—Overall performance reflects benefits of increased operating temperatures and pressures. Note, however, that at 1050 F there is no advantage above 4000 psi. As temperatures go to 1200 F then 5000 psi and above look attractive

in the once-through boiler for application in the subcritical pressure zone, between 2350 and 3000 psi. While there exists one installation of a natural circulation conventional drum boiler designed for 2800 psi it is easily recognized that natural circulation boilers become less practical as critical pressure of 3206 psi is neared.

One solution to this difficulty has been the forced circulation boiler which has been strongly advocated by one boiler manufacturer and just as strongly resisted up to now by several others. Since the choice between the two methods of circulation has hardly any effect on the design or selection of the boiler feeding equipment and since this choice is still highly controversial, we need not give any particular opinion on the relative merits of natural and forced circulation systems.

Another solution of the problems engendered by operation in the pressure range near the critical has been to depart from the traditional boiler cycle where the design effort has been toward keeping the water and steam cycles as separate as possible. This departure has been the use of the once-through boiler, the fundamental principle of which is illustrated on Fig. 5. In the "once-through" type boiler, feedwater is delivered to the inlet of the heat absorbing circuit. Generally, the feedwater passes through an economizer and then into the evaporator section. Evaporation or change of state takes place gradually along the length of the circuit. When the change of state has been completed, further progress of the fluid through the circuit and further addition of heat results in superheating the steam. The mass flow of water entering the boiler at all times is equal to the mass flow of superheated steam leaving the boiler. This type of boiler requires no conventional steam-and-water boiler drum.

The greatest progress in "once-through" boiler design had taken place, until recently, in Europe. The major incentives for this development had been the elimination of the heavy thick-walled boiler drums and the conservation of scarce materials through the use of thinner boiler tubes.

Let us now consider the effect which the once-through boiler will have on the selection of the boiler feed pumps. The losses between the pump discharge and the boiler stop valve remain approximately the same as in the case of the conventional drum boiler. But because of the high velocities required through the boiler and superheater circuits and the attendant high friction losses, the discharge pressures required at the boiler feed pump are increased by as much as 600 psi. When it is considered that pumps have to be rated for flows exceeding the maximum throttle flow by as much as 10 per cent, the resulting friction losses are further increased and the difference in rated discharge pressure between a conventional and a once-through boiler installation may reach as high as 800 psi.

We shall speak later of the progress made in the application of high-speed boiler feed pumps in the modern steam power plant. But we should mention at this time that the increased pressure requirements of once-through boilers will tend to favor the use of high speed pumps for two reasons. The total heads to be generated would require many more stages in a 3600-rpm pump, with an attendant increase in shaft span and shaft deflection, to the detriment of reliability. The higher discharge pressure will increase the stresses at the discharge head bolting, again affecting reliability unfavorably. The use of pump speeds between 6000 and 9000 rpm will remedy both of these disadvantages, by reducing the number of stages and by reducing the pump barrel diameter and the discharge head pressure area.

This increased required discharge pressure may, in a few isolated cases, lead the power plant designers to consider splitting the pressure to be generated between two pumps, so as to locate the closed heaters between a primary and secondary feed pump and reduce heater costs. Such cases should be rare, because thorough analysis has indicated the lack of economic justification for this solution even in the case of units intended to operate at 3500-psi throttle pressure and requiring 4700-psi discharge pressure at the feed pumps.

Because of the increase in power consumption by the boiler feed pump, the use of once-through boilers has the effect of increasing the net heat rate of the unit. For instance, a recent analysis of a large unit intended to operate at 2350-psi throttle pressure showed that the increase of 500 psi in the net pressure generated by the boiler feed pumps over that required for a conventional unit, had the effect of increasing the heat rate by 33 Btus. In addition, the cost of the pumps, hydraulic couplings and drivers would have been appreciably increased.

Thus, in order to justify the use of a once-through boiler, the installed cost of the boiler and of its auxiliaries must be reduced by at least the capitalized value of the loss in the heat rate and by the added cost of pumps and drivers. Obviously, the evaluation of the effect on the heat rate will vary widely for different fuel costs, and load factors, to cite a few examples.

But the general feeling among utility engineers is that

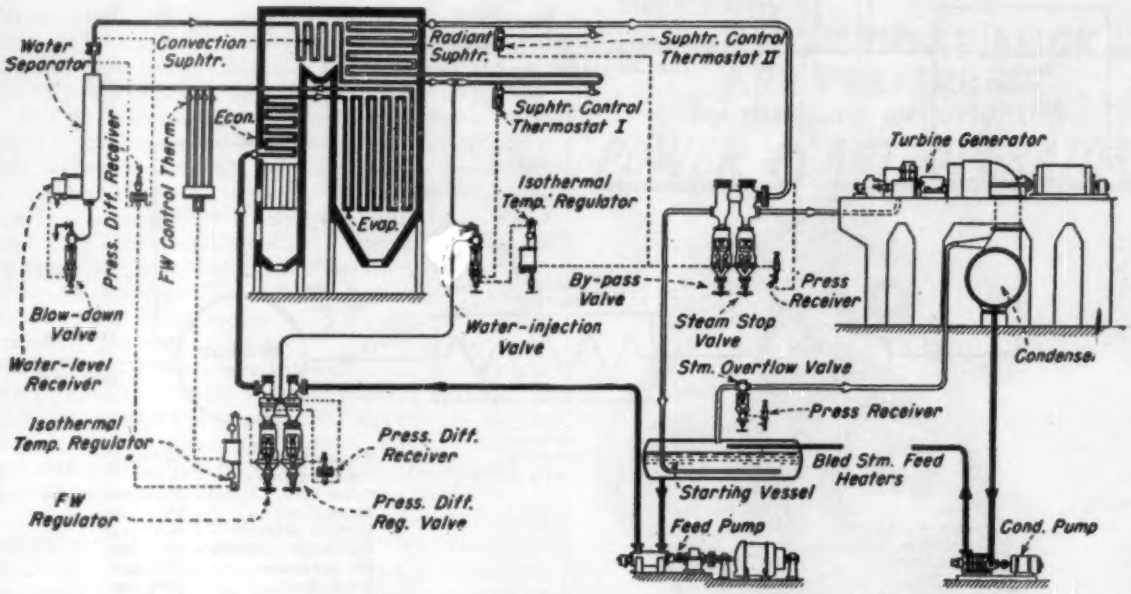

Fig. 5—Diagram shows the fundamental principle of the Sulzer monotube steam generator with its water separator

it is questionable whether once-through boilers can be justified economically at pressures under 2400 psi. As a result, it is almost impossible to predict today how many of the new units intended to operate at sub-critical pressures may be supplied with once-through steam generators.

On the other hand, it is very obvious that no other type of steam generator can be used once throttle pressures exceeding the critical steam pressure are encountered.

The first commercial supercritical pressure steam-electric generating unit will go into service sometime in 1956 in the Philo Plant of the Ohio Power Co., a subsidiary of American Gas & Electric. It will be rated at 125,000 kw, with throttle pressure of 4500 psi. A larger unit (275,000) operating at 5000 to 5500 psi will later be installed by the Philadelphia Electric Co. Finally, a 250,000-kw, 3500-psi unit has been ordered by the Cleveland Electric Illuminating Co. for their Avon plant.

At this writing, it would appear that the 4500 psi pressure for the Philo plant and the 5500 psi for Philadelphia Electric may well be extremes that will not be approached again for a number of years. The 4500-psi throttle pressure is not economically justifiable for a unit of 125,000 kw and it would seem that it would take at least a 300,000-kw unit to make this pressure pay out. At the present time, studies are being carried out by one utility on a 400,000-kw super-pressure unit *and that unit will be designed for 3500-psi throttle pressure,* indicating that higher pressures are still to be economically justified.

Prior to the preparation of boiler feed pump specifications for the super-pressure unit ordered by Cleveland Electric Illuminating, a very thorough study was carried

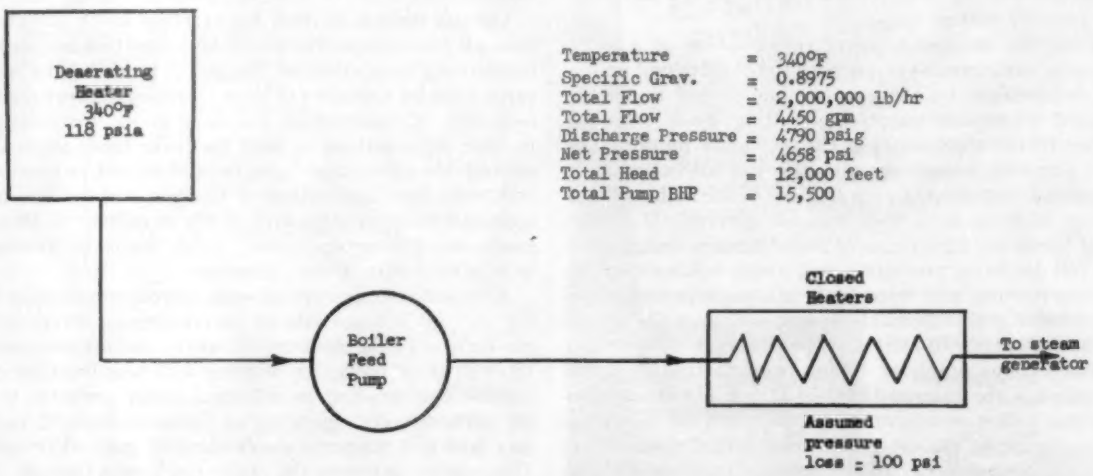

Fig. 6—Single pump discharging through closed heaters (Actual installation uses two half-capacity pumps)

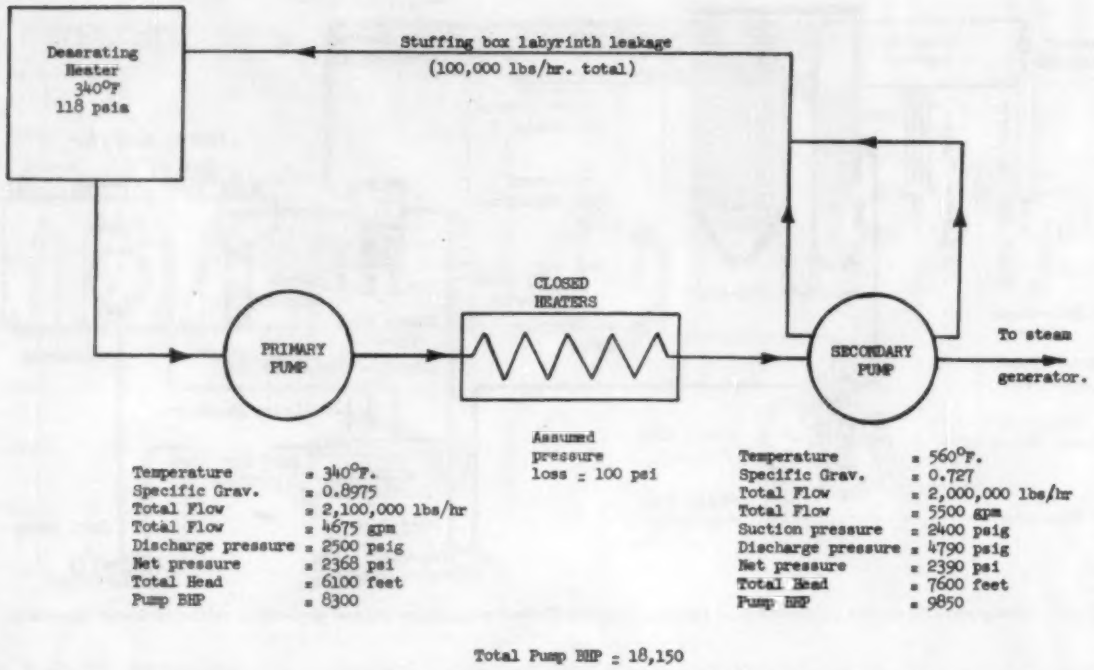
Deaerating Heater 340°F 118 psia
Stuffing box labyrinth leakage (100,000 lbs/hr. total)
CLOSED HEATERS
PRIMARY PUMP
SECONDARY PUMP
To steam generator.
Assumed pressure loss = 100 psi
Temperature = 340°F.
Specific Grav. = 0.8975
Total Flow = 2,100,000 lbs/hr
Total Flow = 4675 gpm
Discharge pressure = 2500 psig
Net pressure = 2368 psi
Total Head = 6100 feet
Pump BHP = 8300
Temperature = 560°F.
Specific Grav. = 0.727
Total Flow = 2,000,000 lbs/hr
Total Flow = 5500 gpm
Suction pressure = 2400 psig
Discharge pressure = 4790 psig
Net pressure = 2390 psi
Total Head = 7600 feet
Pump BHP = 9850
Total Pump BHP = 18,150

Fig. 7—Series pump arrangement as contrasted to Fig. 6 has the closed heater between the primary and secondary pumps. Actual installation uses two half-capacity pumps for primary phase, two half-capacity for secondary

out to compare the use of single pumps designed to generate the entire required pressure in a single casing with the use of primary and secondary pumps arranged in series, the closed heaters being located between the two pumps. Figs. 6 and 7 illustrate the two arrangements.

It will be noted that the capacity of the primary pump is somewhat greater than the required rated capacity of the secondary pump or of the single pump shown on Fig. 6. This is the result of the difficulty of designing the secondary pump with such a high pressure ahead of the stuffing boxes and of the need of providing pressure reducing labyrinths ahead of these boxes. The excess capacity of the primary pump represents the estimated leakage through these labyrinths, a leakage which must be returned to the direct contact heater at the suction of the primary pumps.

Thus, the increased power consumption of a split-pumping arrangement is due both to the increased pumping requirement by the primary pumps and to the increased power consumption resulting from pumping higher temperature water in the secondary pump. The split-pumping arrangement is also less attractive from the initial cost point of view because of the higher cost of pumps in series with their separate drivers. It is estimated that the higher cost of closed heaters designed for the full discharge pressure is just about balanced by the savings in pump and driver costs of a single pumping system as in Fig. 6. Thus, the power savings of the single-pump system are all a net saving in its favor.

The various problems arising from the use of steam pressures of the order of 3500 to 4500 psi, insofar as once-through boilers are concerned are not much different from those arising in the subcritical zone. The major difference, of course, is the final discharge pressure and the pumps must be designed to withstand it satisfactorily.

Combined Steam-and-Gas Turbine Plants

It may appear strange to have us speak of combined steam-and-gas turbine power plants in an article directed primarily at the boiler feed pump. Yet, we cannot discount this subject as it would appear that this type of plant may well have an indirect effect both on the relative size of boiler feed pumps and on the average operating pressure of these pumps in the very near future.

Earlier, we asked ourselves whether we had reached the point where further improvements in station efficiency must be obtained by means other than increasing pressures and temperatures. The answer appears to be emphatically "yes" and the combined steam-and-gas turbine cycle appears to be the most promising.

The gas turbine in itself has received much attention from all power engineers and studies how best to employ this worthy competitor of the steam turbine have been carried out by a number of large power equipment manufacturers. Consideration has been given, for instance to using a gas turbine to drive the boiler feed pump, and appreciable advantages have been indicated as possible. But even this application of the gas turbine has not appeared to be as attractive as the so-called "combined steam-and-gas turbine cycle" which today is receiving most attention in power circles.

A typical arrangement of such a cycle is presented on Fig. 8. Air is taken into an air compressor driven by a gas turbine. The discharge from the compressor passes through an air preheater supplied with heat from the gas turbine exhaust and is delivered under pressure to a pressurized boiler, operating at pressures from 60 to 80 psig where it supports combustion of gas, oil or coal. The exhaust gas from the boiler discharges through the gas turbine, the air preheater and the feedwater econo-

mizer, after which the cooled flue gas is discharged through the stack. Part of the power generated by the gas turbine is used to drive the air compressor and part of this power is used to drive an electric generator.

The steam portion of the cycle is conventional except in that the economizer is heated by exhaust gas from the gas turbine and that the boiler itself is pressurized.

A great number of studies have been carried out on the heat balance of cycles such as illustrated on Fig. 8 and other similar arrangements. They all have served to prove that a very marked improvement in heat rate is possible from such a combination steam-and-gas turbine cycle, an improvement which is independent of the operating pressure of the steam portion of the cycle. For instance, where a straight steam unit operating at 2000 psig, 1050 F/1050 F reheat shows a heat rate of slightly over 8900 Btu's/kwhr, a combined steam-and-gas turbine plant, designed for the same steam conditions but with a pressurized boiler, will reduce the heat rate to somewhere under 8400 Btu's/kwhr.

This combined cycle is especially interesting because the gas turbine can be superimposed on any steam plant operating at any combination of steam pressure and temperature and improve the overall efficiency by about 5 per cent. Of course, the gas turbine portion of the cycle still has to earn a reputation for dependability and long life without forced outages comparable to those of the steam turbine. This, gas turbine manufacturers all state it will do and the future of this combined cycle appears bright today.

These combined cycles will have little effect on the design or application of the boiler feed pumps. They will, of course, tend to hold operating pressures down and will result in lower total steam flows (and therefore smaller pumps) for the same installed size plant.

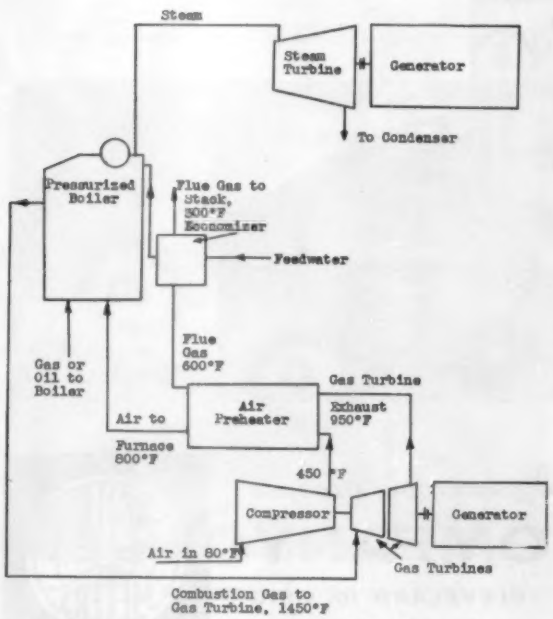

Fig. 8—Schematic diagram of combined steam-and-gas turbine cycle with a pressurized boiler plant

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Soot Ignition Temperature Measurement

By D. R. ANDERSON and W. R. WATSON

National Aluminate Corp.

INTEREST in preventing soot through the use of chemicals dates back to 1856 when an English patent was granted for a mixture of quicklime and soda ash. In the following years many chemicals and mixtures were proposed and used as soot removers with varying degrees of success, but no methods of precise measurement were available for judging their performance. The people who needed these soot removers often had to rely on vague or extravagant performance claims.

In 1932 Nicholls and Staples of the U. S. Bureau of Mines (1)[1] eliminated much of the confusion surrounding the use of chemical combustion catalysts by conducting a series of carefully controlled laboratory experiments. In their test method, which was designed to simulate household stoves and furnaces, the chemical compound being tested was vaporized and the vapors were condensed on previously sooted screens. The visible ignition point of this treated soot was determined by placing one of the treated screens in a preheated air stream. The temperature of the treated soot was gradually increased by regulating the air stream temperature. If the soot did not ignite during a 30 F temperature rise, the first screen was replaced by a second treated screen and the temperature increased another 30 F. After the approximate temperature of visible burning was found, fresh screens were inserted at closer temperature intervals to pinpoint the exact soot ignition temperature. This procedure was used to overcome the gradual disappearance of the soot below the temperature of visible burning. They tested a large number of powdered metals, compounds, and mixtures and found that the ignition point of soot could be reduced as much as 500 F by combustion catalysts.

More recent investigations into the effect of various inorganic salts on the ignition temperature of carbon black were made by H. Akamatu and H. Hamada (2) through the use of a simple thermobalance. Their work was extended by H. Sato and H. Akamatu (3) who analyzed the gases liberated when carbon mixtures were heated to various temperatures and showed a correlation between the ignition temperature of carbon black and the volume of carbon dioxide evolved. It was also shown that the presence of certain metal salts on the carbon black would produce a sizable reduction in the ignition temperature.

Many other investigators have studied different phases and applications of the catalytic effect of chemical compounds on the ignition of different forms of carbon. The general procedure involves saturating the carbon with an aqueous solution of the material, drying, heating under controlled temperature conditions, and measuring the weight loss.

In 1947 a sponsored research program to develop combustion catalysts for commercial and industrial applications was inaugurated at Battelle Memorial Institute by the authors' company. The test equipment and procedures were similar to those used by Nicholls and Staples and the results generally confirmed their

[1] Numbers in parentheses refer to Bibliography at end of the article.

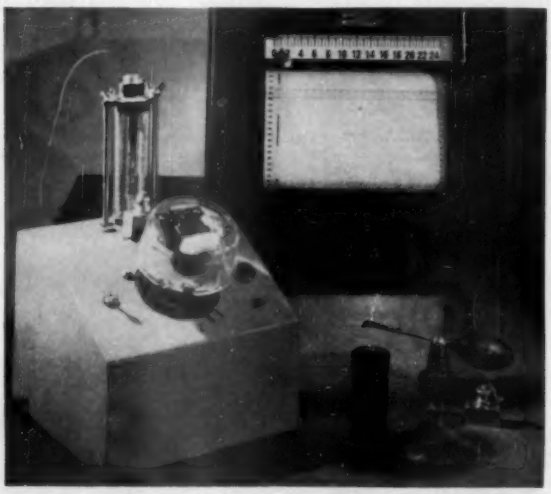

Fig. 1—Sootometer for measuring the ignition temperature →

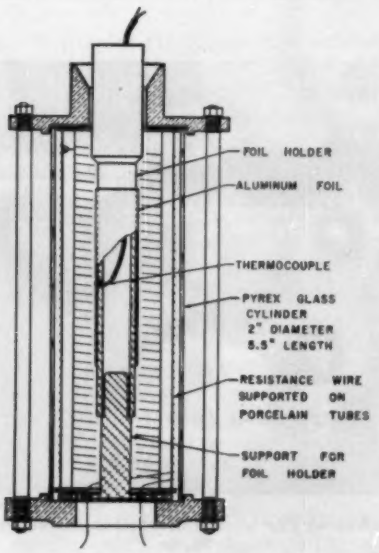

Fig. 2—Details of Sootometer showing relative position of heater, foil, foil holder, and thermocouple

work. Commercial use of the compounds found effective by this test method has enabled many operators to reduce soot accumulations and obtain better performance from their coal burning equipment.

The preponderance of work reported in the literature on combustion catalysts deals with solid fuels with little attention given to the increasing problem of soot formation in oil fired equipment. Many of the improvements in oil refining processes have increased the production of premium fuels such as gasoline, but lowered the burning quality of the fuel oil. As a result, the demand has increased for fuel oil treatments which will provide cleaner burning and less soot formation.

Development of a New Catalyst Test Instrument

A review of test methods suitable for obtaining reliable and accurate data on the action of combustion catalysts in fuel oils revealed only pilot plant types of test procedures. These are good for final evaluation of fuel treatments, but are too cumbersome and slow for preliminary screening tests. Several different laboratory test procedures were developed by the authors' company including one very simple demonstration of combustion catalysis. One side of a 3-in. square of household aluminum foil was sooted over a candle and half of the sooted area sprayed with an oil solution containing a combustion catalyst. By heating the reverse side of the foil over an alcohol burner, the soot on the treated area burned off quickly leaving soot only on the untreated portion. The unique feature of the demonstration was the burner flame which produced a maximum temperature somewhere between the ignition point of untreated and treated soot. By numerous refinements of this early test method, an apparatus has been developed in which the test conditions can be closely controlled and reproduced. The apparatus is shown in its most recent form in Figs. 1 and 2.

The principle of operation is very simple. A new piece of aluminum foil is wrapped on the foil holder and sooted in a suitable flame (Fig. 3*A*). A No. 2 fuel oil solution or finely divided oil suspension of the material to be tested is sprayed on the soot (Fig. 3*B*) and the holder placed in the heater where it is heated at a uniform rate until the soot disappears. The temperature at which the foil is again visible in the area surrounding the thermocouple junction is recorded as the soot ignition temperature. As a convenience in referring to this apparatus, the term "Sootometer" has been adopted.

Details of Construction

The foil holder is a 5-in. length of $^5/_8$-in. diameter thin wall aluminum tubing. A $^1/_{16}$-in. slit along the side of this tube is used to fasten the foil which is wrapped around the holder. Foil temperature is measured by a 28 gage chromel-alumel thermocouple which extends through the foil-holder wall until the junction is flush with the outer surface of the foil.

The heater consists of five $^1/_4$- × 5-in. ceramic insulators mounted to form a $1^5/_8$-in. diameter cage which is wrapped with forty turns of No. 24 gage Nichrome resistance wire. The heater is supported in a $5^1/_2$-in. length of 2-in. diameter Pyrex glass tubing by upper and lower metal flanges. A $^7/_8$-in. opening in the upper flange allows the foil holder to be positioned inside the heater. A similar opening in the lower flange permits circulation of air through the heater. The foil holder rests on an aluminum post fixed at the center of the lower flange by a perforated aluminum disk. The heater temperature is controlled by a 0 to 135 v, motor-driven, autotransformer. The timing motor drives the auto-transformer at the rate of two revolutions per hour, approximately five volts per minute, through a slip clutch which protects the transformer against overrun and permits easy resetting after each test.

A recording potentiometer with a scale range of 0 to 2500 F records the temperature rise of the foil as indicated by the thermocouple.

Test Procedure

A 3- × 4-in. sheet of household aluminum foil (0.0007-in. thickness) is tightly wrapped around the foil holder and held in place by tucking the ends into the holder slit. A small hole is made in the foil to expose the thermocouple junction after which the foil is wiped with a clean cloth to remove fingerprints. Soot is applied by placing the holder in the flame of a small wick burner

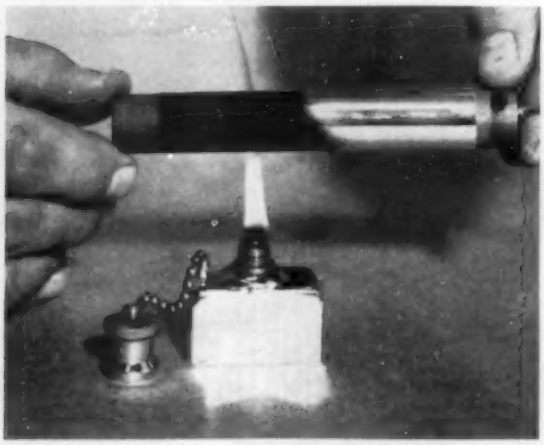

Fig. 3A—(Above) The aluminum foil is sooted in a fuel oil flame

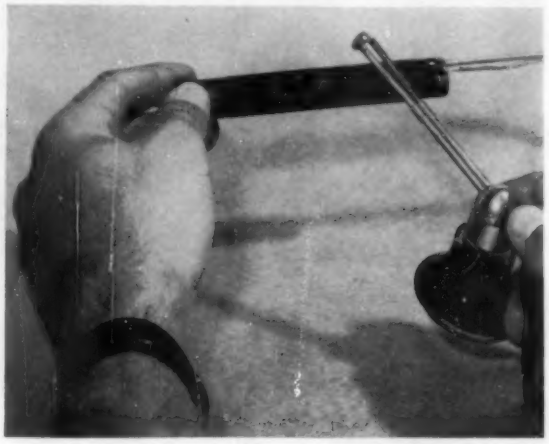

Fig. 3B—(Above) Treatment is applied to the sooted surface by an atomizer

as shown in Fig. 3*A*. Fig. 3*B* shows the soot being wetted by an oil spray containing the material to be tested for catalytic activity.

Using an initial auto-transformer setting of approximately 50 v, power is supplied to both the transformer and its drive motor. The temperature of the foil increases at the rate of 50 to 60 F per minute. A safety shield protects the operator during the 200 to 500 F period when oil vapors are being released from the treated soot. This protection is desirable although the vapors have never ignited in over 400 determinations.

As the temperature of the sooted foil increases, nonvisible combustion occurs and exposes the shiny metal surface of the foil. This change is easily seen through the glass wall of the heater. The temperature at the moment the soot disappears from the area surrounding the thermocouple junction is recorded as the soot ignition temperature. When the main body of the foil changes from a black body to a reflecting surface, there is a sudden drop in the rate of heat absorption by the foil and a definite offset in the time-temperature curve.

Preliminary Instrument Tests

Since this test method is a new approach in measuring soot ignition temperatures, many specific tests were required during the development of the instrument. As an example, the use of aluminum foil was desirable because of its convenience and availability. However, the prospect of finding soot in contact with aluminum, in practice, is extremely remote in comparison to finding it adhering to an iron surface. To determine if the aluminum influenced the test results, both iron and aluminum foil were used under identical test conditions. The results were not significantly different, and aluminum foil was used in all later work.

Source of Soot

Naturally, the variation in ignition temperatures caused by changes in the source of soot was also an item of major concern. Early in this work the ignition temperature of candle soot was found to be as much as 50 F below that of soot from No. 2 fuel oil. This difference in temperature prompted further testing to determine the ignition temperatures of soot from many other sources. Results of these tests are shown in Table I.

The graphite test appearing in Table I illustrates a slight departure from the normal test procedure. To bond the dry, flaky material to the aluminum, a paste made of graphite and number 6 fuel oil was applied as a thin layer over the foil. As the heater temperature increased, the fuel oil gradually disappeared, leaving only the graphite, which remained unchanged up to 1300 F—the temperature at which the heater failed.

TABLE I—IGNITION TEMPERATURE OF SOOT FROM VARIOUS SOURCES

Type of Fuel	Soot Ignition Temp., F
Candle	1050
No. 2 Fuel Oil (straight run)	1055
Heptane	1065
No. 2 Fuel Oil* (cat. cracked)	1090
Benzene	1100
No. 2 Fuel Oil (very unstable cat. cracked)	1100
Acetylene	1110
No. 6 Fuel Oil	1110
Graphite	Above 1300
(Heater burned out at 1300 F)	

* Because of its availability, this fuel was used as the standard source of soot in all later work unless otherwise noted.

Early Tests with Catalysts

Reproducibility of results was another important factor during the development stages. Oil-soluble, metal-organic compounds known to have catalytic activity were tested and retested. Also the possibility of catalytic hold-over from a previous test influencing the results of a later test was checked frequently by interspersing tests containing no catalytic material. From these tests the variation between identical determinations was generally within plus or minus 5 F. To limit the test results to the fundamental catalytic activity of the test materials and exclude the variable of concentration, an excess of catalyst was always applied. With metal-organic spray solutions, one per cent metal by weight was usually adequate. The standard procedure was to moisten all of the soot, but avoid any running or dripping of the solution on the sprayed surface. Approximately 0.5 ml of solution was used during this spraying operation. However, less than one half of the spray contacted and remained on the sooted surface. An early test illustrating the effect of catalyst's concentration involved the dilution of an oil-soluble copper solution from one per cent to one-tenth per cent metal. Sootometer results were identical over the entire concentration range. However, further dilution greatly reduced the effectiveness of the solution.

Influence of Time and Temperature

The effect of heating rate on the ignition of soot presented another unknown variable requiring close examination. Rates between 40 and 60 F per minute gave reproducible results, while with lower heating rates, the soot disappeared at much lower temperatures. This action was further studied by heating soot at the normal rate to a specific temperature below the normal ignition temperature and maintaining this temperature until the soot disappeared. Fig. 4 shows the time required for complete combustion of soot when held at the temperatures shown to the left of the table. Soot treated with an oil-soluble catalyst produced the same general time-temperature pattern. However, the temperatures were 200 to 250 F lower than with untreated soot.

Nicholls and Staples (1) found that untreated soot ignited in their equipment between 1047 F and 1225 F or a mean value of 1136 F. Despite this wide range of 178 F the value of 1136 F agrees quite well with the Sootometer value of 1090 F. The results in Fig. 4 on the amount of time required to burn soot at temperatures below the normal ignition temperature also generally agree with Nicholls and Staples' results. The amount and type of soot used in the two different methods probably account for the small differences in results.

Fig. 4 also shows that both untreated and treated soots will burn over a 200 F temperature range below their normal ignition temperatures if allowed sufficient time. These findings disagree with the latter part of the Nicholls and Staples' statement that, "Soot treated with a salt or compound which lowers its temperature of ignition also disappears at temperatures below that of ignition, but the range of temperature at which that occurs is less than for untreated soot."

These preliminary tests proved that the Sootometer method is simple, quick and reliable. The apparatus

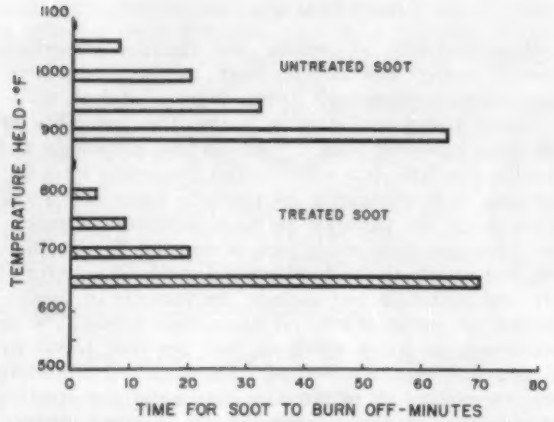

Fig. 4—Time required for soot to disappear when treated and untreated soot is held at the temperatures shown

is easy to construct and occupies a minimum of space. In addition, the amount of sample required per test is small, and the complete test requires only 30 min.

Action of Metal-Organic Compounds

Sootometer determinations were made on many of the more common metals by treating the standard soot with oil soluble, metal-organic compounds as described in the section on test procedure. The oil solution for each test contained one per cent of the desired metal as the salt of either octoic or naphthenic acid. The results of these tests are given in Table II. The work by Nicholls and Staples on action of metal chlorides has also been listed in Table II for comparison with the Sootometer results on metal-organics. Since Nicholls and Staples' procedure requires that the catalyst contact the soot as a vaporized metal or metal compound, the metal chlorides are probably the most reliable class of compounds to use for this comparison, since they are the most uniformly volatile.

Table II shows fair agreement between data from the two test methods with three exceptions: zinc, tin, and copper. The presence of chloride in the Nicholls and Staples' test may account for the differences in results for these particular metals.

Action of Non-metallic Compounds

The catalytic activity of most non-metallic compounds is low as measured by the Sootometer. Ignition temperature reductions greater than 50 F are unusual. However, some organic compounds containing halides, chlorine, and bromine in particular, will provide reductions up to 80 F. Organic nitrogen compounds in general are ineffective catalysts, although some show a definite effect, such as amyl nitrate which lowers ignition approximately 60 F. Sulfur and phosphorus compounds show very little catalytic action by themselves. The importance of the non-metallic compounds which we have studied rests in their ability to influence the oil-soluble, metal catalysts.

Co-Action of Metal and Non-metal Compounds

The catalytic activity of many oil-soluble, metal-organic compounds is increased by the addition of certain non-metals. The effect of copper plus chlorine illustrates this type of combined action. With an ignition temperature reduction of 250 F for oil-soluble copper and 80 F for oil-soluble chlorine, the expected combined reduction might approach 330 F. Sootometer values for this mixture, however, have exceeded 375 F. This synergistic action of chlorine probably is responsible for the previously noted deviations between the metals and their chlorides in Table II.

TABLE II—REDUCTION OF THE IGNITION TEMPERATURE OF SOOT BY THE ADDITION OF VARIOUS METALS

Sootometer		Nicholls and Staples Method	
Material	Ign. Temp. Reduction, F	Material	Ign. Temp. Reduction, F
Untreated soot (ign. temp. 1090 F)	0	Untreated soot (ign. temp. 1136 F)	0
Sodium	260	Sodium chloride	166
Calcium	190	Calcium chloride	224
Zinc	40	Zinc chloride	235
Manganese	220	Manganese chloride	235
Ferric iron	240	Ferric chloride	236
Potassium	255	Potassium chloride	247
Tin	60	Stannous chloride	276
Nickel	240	Nickel chloride	291
Lead	350	Lead chloride	324
Copper	250	Cupric chloride	512

Phosphorus is another element having unusual properties when combined with metal-organic catalysts. Its oil-soluble compounds produce the opposite effect from that of chlorine. As an illustration, the addition of tricresyl phosphate to copper octoate reduces the catalytic effectiveness of copper at least 50 F.

Summary and Conclusions

A new instrument has been developed to measure the ignition temperature of soot. The instrument is particularly well suited for determining the temperature at which soot burns when in contact with various chemical compounds and mixtures. In the development of combustion catalyst fuel treatments, this screening procedure materially reduces the required number of lengthy tests in more elaborate combustion equipment by indicating which materials show greater promise.

Others who are confronted with the problems associated with combustion catalysis can easily adopt this instrument to their particular needs. Its application to fuel treatment studies by the authors' company has led to the following conclusions:

A. The apparatus described provides a simple, fast, and reliable method of determining the effectiveness of catalysts in lowering the ignition temperature of soot.

B. Lead, sodium, potassium, and copper have strong catalytic action. This is in agreement with the results of other workers.

C. Non-metallic materials are generally ineffective, but certain ones can increase or decrease the effectiveness of metal catalysts.

Acknowledgments

The authors wish to thank Clarence Jacklin for his very helpful advice during the course of this work and for assistance in preparing this paper.

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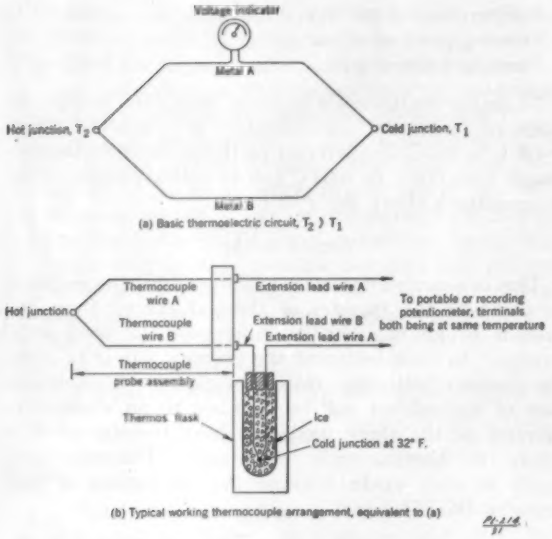

Fig. 1—Schematic thermoelectric circuits

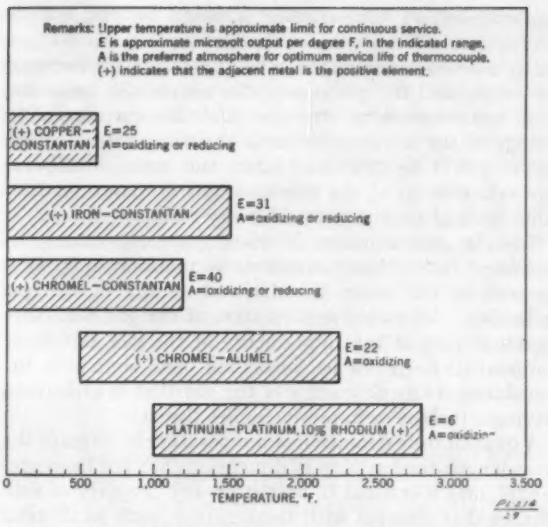

Fig. 2—Preferred temperature range for various types of thermocouples

Measurement of Gas Temperatures with Thermocouples

By RICHARD C. COREY*

Bureau of Mines

The thermocouple, simplest measuring device for hot gas temperatures, is subject to errors of varying degree. This article describes the sources of error in thermocouple pyrometry and gives practicable means for minimizing them. In addition the various thermocouple types and their characteristics are included.

INDUSTRIAL processes that operate as the result of heat transfer from hot gases require accurate measurement of the temperature of the gases for computing heat balances, thermal efficiencies and other important process variables. Familiar examples of such processes are boiler furnaces, blast furnaces, kilns, gas or steam turbines and jet engines, as well as auxiliary heat-transfer equipment, such as superheaters, regenerators and recuperators.

The simplest and most widely used method of measuring the temperature of a hot gas is the thermocouple. Inherently, a thermocouple is highly accurate; but, as with any pyrometric device, it is subject to errors that may be very large, depending upon the conditions under which it is employed.

Elementary Concepts

In itself a thermocouple is a heat-transfer system, since the various modes of heat transfer, conduction, convection and radiation occur when it is placed in a hot gas. For better understanding of the sources and the magnitude of the temperature errors that may arise from the use of a thermocouple, it is desirable briefly to review some of the elementary concepts of temperature and heat transfer.

Meaning of Temperature

Unlike pressure and volume, temperature cannot be measured in terms of simple fundamental quantities, such as force and length, but must be measured indirectly, and the interpretation of these measurements into something that has an absolute significance is quite complicated. For all practical purposes, temperature is best considered as a measure of the driving force for heat energy. In this connection, Maxwell defined temperature as the thermal state of a body considered with reference to its ability to transfer heat to other bodies. Qualitatively, we know that heat will flow from a "hotter" body to a "colder" one, and when this flow of heat ceases both bodies will have the same temperature, and we define them as being in thermal equilibrium.

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Measurement of temperature is based on this simple assumption. Thus, when a thermocouple is placed in a gas at a given temperature, when heat transfer between the couple and the gas ceases, the couple will be at the same temperature as the gas, and the corresponding voltage of the couple represents the temperature of the gas. As will be described later, the voltage-temperature relationship of the thermocouple is determined by calibration against certain arbitrary standards.

From a kinetic point of view gas temperature, as measured by a thermometer or a thermocouple, is a measure of the mean translational energy of the gas molecules. Vibration and rotation of the gas molecules represent part of the total energy of the gas, but these components need not be considered here, since it is the translational kinetic energy of the gas that is utilized in driving a turbine or in producing jet thrust.

A quantitative definition of temperature in terms of the mass-length-time system of dimensions has not been successful, and it is usual to base it on any property of substances that changes with temperature, such as thermal expansion of a gas, vapor, liquid or metal (mercury thermometer or bimetal thermometer); electrical resistance (platinum-resistance thermometer); or contact electromotive force (thermocouple).

To establish a numerical scale of temperature, it is first necessary to define the length of a degree. For example, the interval between the freezing point and the boiling point of pure water may be divided into an arbitrary number of degrees, 100 in the case of the Centigrade scale and 180 for the Fahrenheit scale. The choice of the zero point is also arbitrary. Any other temperature then is defined by the following equation:

$$t = \frac{N(X - X_i)}{(X_s - X_i)} \qquad (1)$$

where:

- t = unknown temperature on the scale being defined
- X_i = Length, volume, resistance or emf of a standard substance at the ice point of pure water
- X_s = Value of the respective property of the standard substance at the atmospheric boiling point of pure water
- X = The measured value of any of these properties at the unknown temperature
- N = Number of degrees in interval between the ice point and the boiling point

Equation (1) defines the temperature in terms of linear relationship with the property of a substance; hence no two temperature scales will necessarily agree at temperatures other than the defined fixed points.

Several factors, discussion of which is beyond the scope of this paper, make it impractical to construct an absolute thermometer, that is, one that is independent of the properties of the thermometric substance. However, an International Temperature Scale has been adopted, which uses the following fixed points at a pressure of one atmosphere, for the calibration of scientific and industrial instruments:

Boiling point of oxygen	−182.97°C
Ice point	0.00°C
Boiling point of water	100.00°C
Boiling point of sulfur	444.60°C
Freezing point of silver	960.5 °C
Freezing point of gold	1063. °C

To define the intervals between these fixed points, the platinum-resistance thermometer is employed from −190 C to 660 C, the platinum-platinum, rhodium thermocouple from 660 C to 1063 C and an optical pyrometer for temperatures above the gold point.

Heat Transfer

This is a complex science which enables the engineer to compute the transfer of thermal energy from one system to another, or its conversion to mechanical energy. In both instances the primary aim is to effect the transfer with the greatest efficiency. This discussion of the subject will be confined to an elementary account of the three modes of heat transfer as they apply to thermocouple pyrometry. Different laws apply to each mode, because the mechanism of heat transfer differs for each.

Conduction

Conduction is the transfer of heat from one part of a body, usually a solid, to another part of the same body, or from one body in physical contact with another. A familiar example of conductive heat transfer is the flow of heat that occurs when a wire is heated at one end, or an insulating brick is heated on one face, with the result that the temperature of the cold end or face rises.

The fundamental relation for conductive heat flow through a uniform material, under conditions where the temperature does not change with time (steady state), is:

$$q_k = k\,A(\Delta t/L) \qquad (2)$$

where:

- q_k = Rate of heat flow, Btu/hr
- k = Thermal conductivity of the material through which the heat is flowing, Btu/(hr) (sq ft) (°F/ft)
- A = Area of material at right angles to the direction of heat flow, sq ft (For a wire heated at one end, this is the cross-sectional area of the wire)
- Δt = Temperature difference between the hot and the cold end or side of the material, °F
- L = Length of path through which the heat flows, ft

It is evident that the flow of heat varies directly with the thermal conductivity and the area of the material, and the temperature gradient, and indirectly with the heat path. Other things equal, the thicker and the shorter a wire that is heated at one end, the greater the heat loss. This equation may have different degrees of complexity, depending upon where the heat is applied to the material, whether the heat source is steady or fluctuating, the geometry of the material being heated, and the variation of the thermal conductivity, k, with temperature.

Convection

Convection is the transfer of heat from one point to another within a gas or a liquid, by the movement and mixing of one part of the fluid with another. Owing to the numerous variables that must be considered in evaluating convective heat transfer, exact mathematical

relationships are very rare, but numerous empirical equations are available to the engineer for approximate solutions of the more common heat-transfer problems.

In *free* convection, mixing results from the movement of the fluid produced by differences in densities in the fluid. A familiar example of free convection is the gravity hot-air heating system. Heated air rises from the furnace to the room, where it is cooled by the walls and windows, descends, and returns through the cold-air ducts to the furnace. In *forced* convection, mechanical means are employed to mix the hot and cold masses. This is by far the most important kind of convective heat transfer in engineering; it is used in almost every type of heat exchanger, at least for one of the fluids and often for both.

The general equation for convective heat transfer is:

$$q_h = hA\,\Delta t \tag{3}$$

where:

q_h = Rate of heat flow, Btu/hr
h = Overall coefficient of heat transfer, Btu/(hr) (sq ft) (°F)
A = Area or surface to or from which heat is being transferred, sq ft
Δt = Temperature difference between a surface and the fluid in contact with it

However, the simplicity of equation (3) is delusive. Convective heat transfer is a very complex process, since it involves the transfer of heat from one particle in a fluid to another and therefore depends upon the complex flow properties of fluids. The coefficient, h, depends upon such characteristics as the shape and dimensions of the surface; and the kind, direction velocity, viscosity, temperature, density, specific heat, thermal conductivity and specific heat of the fluid. As mentioned previously, numerous empirical equations have been developed to handle convective heat-transfer problems, and the most notable contribution in this field has been the use of various groupings of these variables into dimensionless parameters, such as Reynolds number (Re), Nusselt number (Nu), and Prandtl number (Pr), which are especially important in cases of forced convection. For example, if one wished to compute the heat-transfer coefficient, h, for a gas flowing normal to a pipe, the following equation is useful:

$$(\mathrm{Nu}) = 0.3\,(\mathrm{Re})^{0.57} \tag{4}$$

or

$$\frac{hD}{k} = 0.3\left(\frac{vD\rho}{\mu}\right)^{0.57} \tag{5}$$

where:

h = Heat transfer coefficient, Btu/(hr)(sq ft)(°F)
D = Diameter of pipe, ft
k = Thermal conductivity of gas, Btu/(hr)(sq ft) (°F/ft)
v = Velocity of gas, ft/hr
ρ = Density of gas lb(ft³) (32.2)
μ = Dynamic viscosity of gas, (lb)(hr)/(sq ft)

Radiation

Radiation is the transfer of heat from one body to another, not in contact with it, by means of electromagnetic wave motion in space. The intervening space may or may not be heated appreciably, depending upon its ability to absorb radiation. Since thermal radiation is the same type of motion that comprises light, it follows the same laws with respect to reflection, refraction, polarization, and variation of intensity with the square of the distance from its source.

The most familiar example of heat transfer by radiation is the radiant energy received from the sun, which traverses interstellar space, where a temperature of −460 F prevails.

The basic general equation for radiation is:

$$q_r = \epsilon\sigma A T^4 \tag{6}$$

where:

q_r = Rate of heat flow, Btu/hr
ϵ = Emissivity, a factor depending upon the kind of surface and its temperature
σ = Stefan-Boltzmann's constant 0.174 (10^{-8}) Btu/(hr) (sq ft) (T^4)
A = Area of radiating surface, sq ft
T = Temperature of radiating surface, degrees R (°F +460)

The engineer, however, is usually concerned with the net radiant heat transfer between two bodies at different temperatures, and separated by a medium that absorbs very little of the radiation. The general equation in this connection is:

$$q_r = F_e F_a \sigma A_1 (T_1^4 - T_2^4) \tag{7}$$

where:

q_r = Net rate of heat transfer, Btu/hr.
F_e = Factor that takes different emissivities of the two bodies into account
F_a = Factor that takes geometrical relationship of the bodies into account
A_1 = Area of surface 1, sq ft
T_1 and T_2 = Temperatures of surfaces 1 and 2, degree R

A frequent situation is calculation of the net heat transfer between a small, enclosed body and the enclosure (for example, a thermocouple in a large furnace, where A_2, the area of the furnace walls, is very large compared to A_1, the area of the thermocouple). Equation (7) simplifies to:

$$q_r = \epsilon_1 \sigma A_1 (T_1^4 - T_2^4) \tag{8}$$

Some Concepts of Thermoelectricity

A thermocouple is a very simple device comprising two lengths of wire made from different metals and connected at both ends to complete the electric circuit. When one of the junctions is at a different temperature from the other, a direct current will flow through the circuit, and the voltage developed will depend upon the resistance of the circuit. A simple thermocouple circuit is shown in Fig. 1 (*a*).

The flow of current produced by a temperature difference between the two junctions of dissimilar metals is ascribed to two phenomena, the *Peltier effect* and the *Thompson effect.*

Peltier discovered that, when a current is passed across

the junction of two dissimilar metals in one direction, the junction cools and absorbs heat and that, when it is passed in the opposite direction, the junction is heated. Conversely, when a junction is heated, current will flow in one direction, and when cooled, in the other. This effect is the principal source of electromotive force (emf) in a thermoelectric circuit, and the magnitude and direction of the emf depends upon the metals that form the junctions and the temperature. To illustrate this effect, imagine the junctions in Fig. 1 (*a*) to be at the same temperature and that an outside battery is substituted in the circuit for the current indicator. Then the temperature of the junctions will change by an amount that is not due entirely to the power dissipated in the circuit as I^2R loss.

Thomson concluded from thermodynamic reasoning that the emf generated by the contact of the two metals was not the only source of emf in a thermoelectric circuit and showed experimentally that heat is absorbed when an electric current flows from the colder to the hotter portions of certain metals, and heat is generated when the current flows from the hotter to the colder portions. In certain other metals this phenomenon is reversed.

Referring again to the simple thermoelectric circuit in Fig. 1(*a*), Peltier emfs will exist at each of the two junctions and Thomson emfs along the part of each wire that lies in a temperature gradient, and the net effect is the resultant emf that appears at the terminals of the measuring instrument.[1] If the temperature of one junction is held constant, as shown in Fig. 1(*b*), the net emf then becomes a function of the temperature of the other junction, which is the basis of thermocouple pyrometry. It will be shown later that any selected, constant temperature can be employed at the cold junction; most temperature—emf tables for the various kinds of thermocouples are based upon a reference junction temperature of 32 F.

Of interest from the standpoint of both thermocouple theory and practice are two laws of thermoelectricity, which are known as the *law of intermediate temperatures* and the *law of intermediate metals*.

The law of intermediate temperatures may be stated as follows:

The thermal emf developed by a thermocouple with its junctions at two temperatures, say T_1 and T_3, is the algebraic sum of the emf of a thermocouple with one junction at T_1 and the other at T_2 and the emf of the same couple with its junctions at T_2 and T_3. In effect, this law states that, if one of the junctions of a thermocouple is at 32 F and the other at 100 F and the junctions of another thermocouple are at 100 F and 500 F, the sum of the voltages would be the same as that developed by a single thermocouple with its junctions at 32 F and 500 F. This law is useful for correcting the measured emf of a thermocouple whose cold junction is above or below a given reference temperature, say 32 F, to the emf that would have resulted if the cold junction had been at 32 F.

The law of intermediate metals may be stated as follows:

The algebraic sum of the electromotive forces in a thermoelectric circuit composed of any number of dissimilar metals is zero if all of the circuit is at a uniform temperature. The significance of this law is that an instrument for measuring the emf of a thermoelectric circuit may be inserted into the circuit at any point, as shown in Fig. 1, without changing the emf, provided that the junctions produced by the instrument terminals and the thermocouple wire are at a uniform temperature. It is assumed, of course, that the instrument itself draws no current.

This law may also be expressed as follows:

$$E_{AD} = E_{AB} + E_{BC} + E_{CD} \qquad (9)$$

where A, B, C and D are homogeneous but dissimilar metals, and the couples AB, BC and CD have their junctions at the same two temperatures, T_1 and T_2.

The laws described above may be combined by stating that the algebraic sum of the thermoelectromotive forces developed in any given circuit containing any number of dissimilar homogeneous metals is a function only of the temperatures of the junctions.

Types and Characteristics of Thermocouples

Although a thermal emf is generated when the junctions of any two dissimilar metals or alloys are at different temperatures, for practical purposes only those combinations of metals or alloys with the following characteristics are suitable for the thermocouple pyrometry:

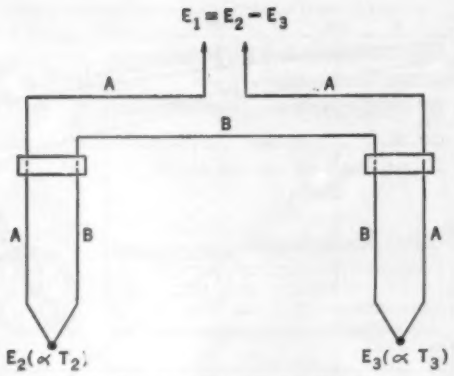
1. The thermal emf increases continuously as the temperature increases, over the temperature range for which the thermocouple is best suited.
2. The emf is large enough, in the operating range, to be measured with reasonable accuracy, and the rate of change of emf with temperature (slope of the emf–temperature curve) is as large as possible.
3. The emf–temperature relationship is not altered appreciably as the result of spontaneous changes within the metals, or of contamination from action of the substances in which the thermocouple is in contact during use.
4. The metals or alloys are reproducible and obtainable in uniform quality.
5. The metals or alloys are relatively corrosion resistant.

The combinations of metals and alloys used most extensively in this country are shown in Fig. 2. The emf–temperature curves of these thermocouples are essentially linear in the temperature range shown, which is a very desirable characteristic in connection with calibrating thermocouples and correcting the cold-junction temperature to a standard reference state.

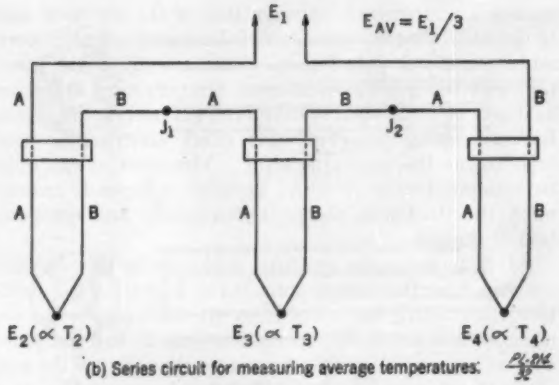
It will be noted that the noble-metal couple (platinum-platinum, 10 per cent rhodium) gives the lowest voltage per degree of temperature, and chromel-constantan the highest. The noble-metal couple, however, is the most stable of any of the other types of thermocouples and is used for defining the International Temperature Scale, for very accurate temperature measurements, and for measurements where the lower melting point materials cannot be used. Owing to the relatively high cost of platinum elements, the noble-metal couple is generally used only for special applications, especially as a standard for calibrating other types of couples.

Of the base-metal couples, chromel-alumel finds the widest application for measuring the temperatures of hot gases, from 500 F to about 2200 F. It has relatively high

[1] In practical thermocouple pyrometry, the errors caused by the Thomson effect are negligible.



(a) Schematic circuit for measuring difference in temperature between two points.



(b) Series circuit for measuring average temperatures.

Fig. 3—Thermocouple circuits for measuring differential and average temperatures

resistance to corrosion by oxidation, but a suitable protection tube should be used with it when the gas is reducing, or worse yet, alternately oxidizing and reducing.

The period of usefulness of a couple depends largely upon such factors as the temperature, the diameter of the wires, and the nature of the atmosphere with which it is in contact. Frequently, oxidation of a base-metal couple is reduced to a considerable extent by the use of thin-walled protection tubes, which may be fabricated of a metal, alloy, or a refractory material, such as porcelain, silicon carbide, graphite, or quartz. Owing to the thermal lag caused by a protection tube, bare wires are preferred where rapid response to temperature changes (sensitivity) is desired. As will be shown later, protection tubes may also introduce appreciable errors due to thermal conduction losses, unless the tubes are properly used.

It is of interest to note that thermocouples can be used also to measure temperature differences and average temperatures. Suppose, for example, one wished only to know the difference in temperature between a gas flowing in a duct and the wall temperature of the duct, the arrangement shown in Fig. 3(*a*) might be used, one hot junction being peened to the metal wall of the duct and the other hot junction being exposed to the gas. All other junctions in the circuit, such as where the wires are attached to the terminals of the voltage-measuring instrument, must be at a uniform and known temperature (law of intermediate metals.)

If it were desired to measure the average temperature of a gas, where a temperature gradient is known to exist, two or more couples suitably located in the gas stream, and connected as shown in Fig. 3(*b*), would give the sum of the emf's at the measuring instrument; dividing this voltage by the number of couples would give the approximate average temperature. In circuits of this type, the hot junctions must not be in electrical contact, such as two or more couples attached to a metal duct in order to determine the average metal temperature.

For further information on the applications and the limitations of the various types of thermocouples, the reader is referred to manufacturers' literature, the ASME Power Test Code, and several excellent articles and textbooks on pyrometry, which are given in the appended Bibliography. (*Editor's Note: This bibliography appearing on p. 55 is divided for convenience into book and magazine references.*)

Sources and Evaluation of Errors

The simplest method of measuring the temperature of a stagnant or a flowing gas in an enclosure is to insert a thermocouple into the gas stream. The hot junction of the thermocouple may be bare, or protected from chemical and mechanical attack by a metal or ceramic protection tube. The true temperature of the gas would be measured by the hot junction under the following idealized conditions:

1. The walls of the enclosure have the same temperature as the gas.
2. The gas temperature is uniform in all directions.
3. The gas is stagnant or moving very slowly.
4. No temperature gradient exists along the thermocouple wires, between the hot junction and where the wires enter the enclosure. Thermal equilibrium then exists between the wall, the gas and the thermocouple junction.

In practice, however, this condition may be approached, but it is never reached, and the junction does not measure the true gas temperature. The principal sources of error and their effects are as follows:

1. The walls of the enclosure, which may be a furnace, a duct, a pipe or a chimney, are at a different temperature, usually lower, than the gas. The thermocouple junction then "sees" the walls, and heat will be exchanged by radiation, (Eq. 8) with the result that the junction will

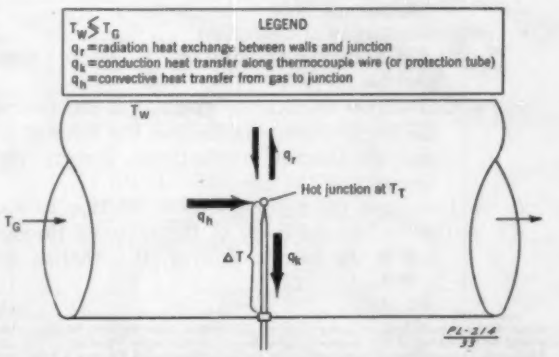


Fig. 4—Schematic diagram of sources of error in measuring gas temperature in cooler or hotter surroundings

assume a temperature between that of the gas itself and of the walls that it "sees." This heat exchange is shown schematically as q_r in Fig. 4. Theoretically, if the junction and the gas have different temperatures radiation heat will be exchanged between the gas and the junction. In most cases, however, this effect contributes very little to the thermocouple error. Moreover, it can only be estimated very roughly, because it depends mainly upon the thickness, shape, temperature, and composition of the gas.

2. A temperature gradient exists along the thermocouple wires, the temperature being higher at the junction than where the wires enter the enclosure. Consequently heat is lost by conduction (Eq. 2) and the junction will assume a lower temperature than that of the gas, other things equal. This is illustrated as q_k in Fig. 4.

3. The gas may be moving at a high linear velocity, and its kinetic energy due to velocity, which is proportional to the square of this velocity, will be partly transformed to thermal energy by impact with the junction. Since the temperature change due to this effect is negligible below velocities of about 250 fps, it need not be considered further here, except to note that it must be corrected for in connection with measuring gas temperatures from turbo jets, ram jets, wind tunnels, and high-pressure steam systems.[1]

Referring to Fig. 4, it is evident that when the walls have a different temperature than the gas and conduction occurs along the wires or protection shield, the three modes of heat transfer occur—convection, radiation, and conduction. When the couple reaches a constant temperature, which lies between that of the gas and of the walls, a heat balance may be written to show that the heat lost from the junction by radiation and conduction is balanced by convective heat transfer from the gas to the junction. Thus $q_h = q_r + q_k$, and the error (which is the difference between the gas temperature and the couple temperature) may be derived from equations 2, 3, and 8, follows:

$$\text{Error} = T_G - T_T = \frac{\epsilon\sigma(T_T^4 - T_W^4)}{h} + \frac{kA_1(T_T - T_W)}{hA_2L} \quad (10)$$

where:

T_G = Actual gas temperature
T_T = Thermocouple temperature
T_W = Wall temperature
A_1 = Cross-sectional area of thermocouple wires
A_2 = Total exposed area of hot junction
ϵ = Emissivity of the junction
σ = Stefan-Boltzmann's constant, $0.174(10^{-8})$Btu/(hr) (sq ft) (T^4)
h = Convection coefficient, which is a function of the linear velocity of the gas, the value of A_2, and the thermal conductivity, density, and viscosity of the gas
L = Length of thermocouple from junction to wall
K = Thermal conductivity of the material through which the heat is flowing, Btu/(hr)(sq ft)-(°F/ft)

[1] The concepts *static* temperature and *total* temperature must be observed when dealing with high-velocity gases. The static temperature is that which would be indicated if the thermocouple moved at the same velocity as the gas. The total temperature is that indicated by a thermocouple having a fixed position in the gas stream and capable of stopping the gas completely and adiabatically, so that the kinetic energy of directed velocity is converted entirely to thermal energy.

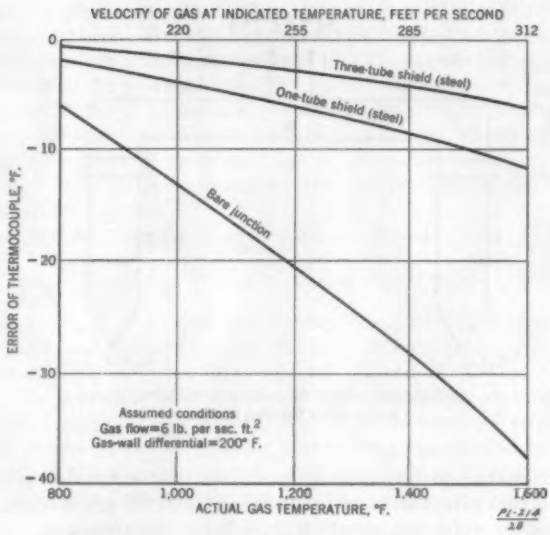


Fig. 5—Radiation error of various types of thermocouples. (Based on Fiock and Dahl, *Trans. ASME*, vol 71, No. 2, pp. 153–161, 1949)

This equation indicates that, in general, the following factors contribute to reduction of temperature error: (*a*) Small difference in temperature between the gas and the walls of the duct, stack, etc.; (*b*) small emissivity of the thermocouple junction; (*c*) high convection coefficient with respect to the gas and the junction; and (*d*) adequate exposed length of the thermocouple wires in the gas.

Regarding the area terms, A_1 and A_2, good practice requires a small junction and the smallest gage wire consistent with reasonable service life for the couple. The k-values of the available types of thermocouple wire are about the same order of magnitude, consequently no appreciable advantage may be gained from selecting a wire with the lowest k value. Generally, the error due to conduction will be negligible if short, heavy-gage wire, or thick-walled protection tubes are avoided.

Of the factors mentioned above for reducing the thermocouple error, those having the greatest effect are the temperature difference between the gas and the walls, the emissivity of the junction, and the convection coefficient, which involves the linear velocity of the gas with respect to the junction. Let us consider these factors separately.

Temperature Difference, $T_G - T_W$

The radiation error varies rapidly, other things being equal, with both the temperature difference, and the temperature level, owing to the fourth-power relationship, shown in the second term of Eq. (10). Referring to Fig. 5, for a particular set of conditions with respect to gas velocity (about 250 fps), emissivity, etc., the calculated error of a bare couple in a gas at 1000 F, with walls at 800 F, is about 13 degrees F. If the gas and wall temperatures were 1500 and 1300 F, respectively, the error is about 33 degrees F. Thus, for the same temperature difference of 200 degrees F between the gas and the walls, the error is appreciably greater at the higher gas temperature.

Two things can be done to reduce the radiation error

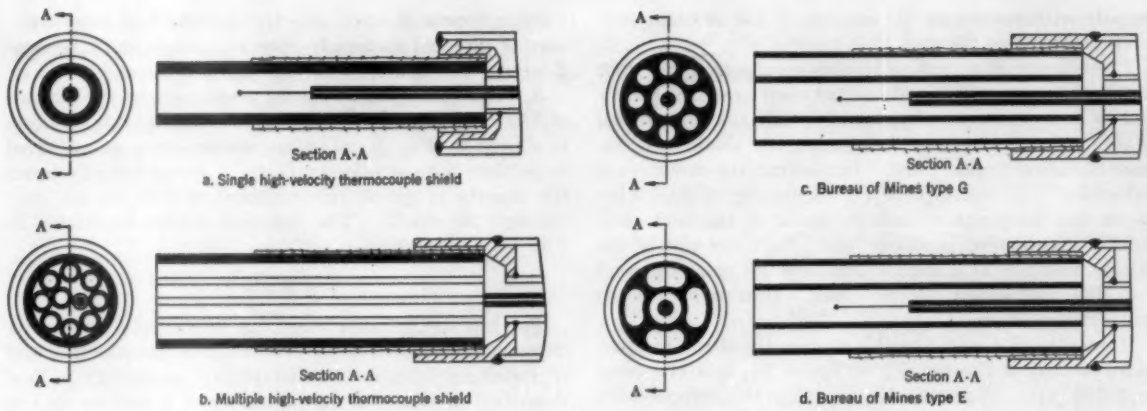


Fig. 6—Various types of ceramic shields for high velocity thermocouples

due to the gas-wall temperature difference. Theoretically, insulation of the walls, inside or outside, would increase their temperature and thereby decrease the temperature difference, but this is usually impractical to do except under special conditions. A practical and more effective procedure is to interpose one or more concentric, metal or ceramic shields between the thermocouple junction and the walls of the enclosure. These are known as radiation shields, which are widely employed, in a variety of designs.

Comparative results of both bare and steel-shielded couples are shown in Fig. 5, and for the particular conditions of these tests, it can be seen that the error at a given gas temperature is reduced by shielding.

The Bureau of Mines has experimented with various types of ceramic shields, in connection with furnace research; four such shields are shown in Fig. 6. The shield at (*a*) constitutes a single radiation barrier between the junction and the walls of the enclosure. The other types, in effect, interpose additional radiation barriers, and the selection of any particular one depends largely upon the conditions under which it is to be used, es-

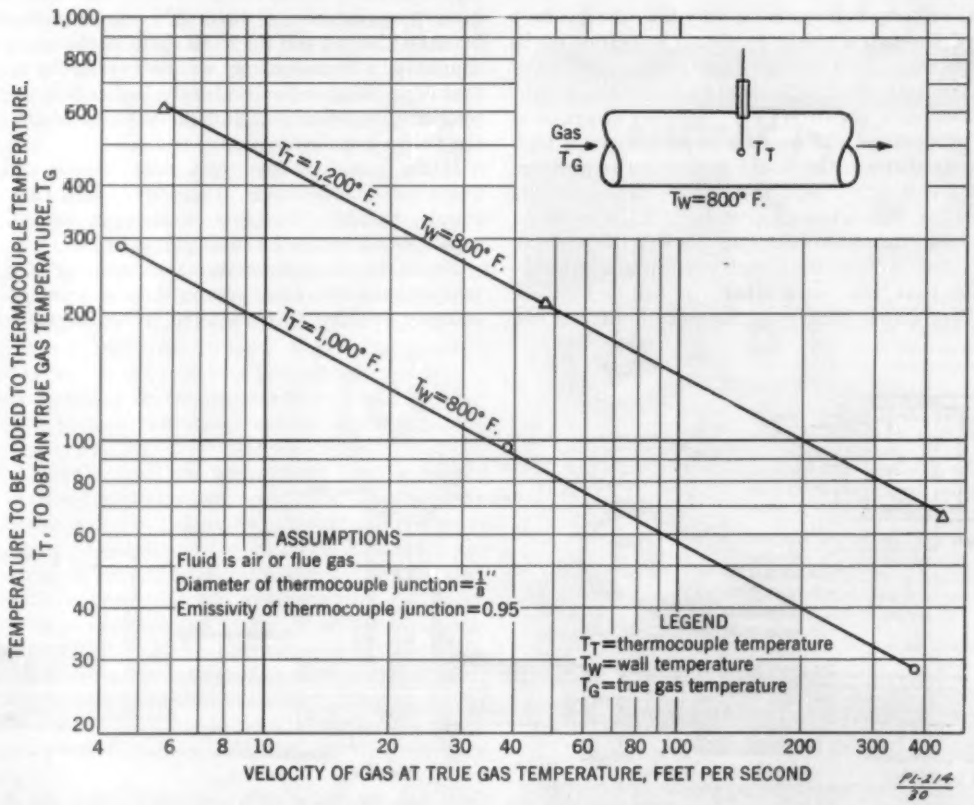


Fig. 7—Effect of velocity of gas on temperature of a bare thermocouple in a duct whose walls are cooler than the gas

pecially with respect to the amount of ash or other particulate matter in the gas.

The efficacy of radiation shields results from the fact that interposing a single shield between a radiating body and its surroundings will reduce the radiation to one-half of its original value, and two concentric shields will reduce radiation to one-third. In general, the radiation is reduced to $1/(1 + n)$, where n is the number of shields between the hot-junction and the walls of the enclosure. In effect, a shielded junction "sees" the inner wall of the shield, which is at a higher temperature than the wall that the unshielded couple "sees," thus reducing the temperature error.

Evidently, if it were possible to raise the shield temperature to that of the gas, $T_G = T_W = T_T$, and the error would be zero. A practical approach in this direction lies in increasing the linear velocity of the gas over the thermocouple junction, thus increasing the convective heat transfer to both the junction and the shield; in other words, the value of h in Eq. (10) is increased.

Convective Heat Transfer

The effect of gas velocity on the error of a bare thermocouple is shown in Fig. 7. It is significant that the corrections to the indicated temperature decrease markedly as the velocity of the gas increases, other things being constant. For the conditions shown in Fig. 7, to obtain the actual gas temperature 200 degrees F must be added to a thermocouple reading of 1000 F, when the gas velocity is 9 fps. If the velocity is increased 10 times, about 60 degrees F must be added to obtain the actual gas temperatures.

If the gas velocity in a system is very low, the gas may be aspirated through a shield to obtain velocities up to sonic. Such thermocouples are commonly called high-velocity thermocouples (HVT), or multiple-shielded high-velocity thermocouples, (MHVT). Another designation is suction pyrometer. As mentioned previously, a high linear velocity through the shield and over the junction increases the convective heat transfer to these elements and reduces the difference, $(T_T - T_W)$; T_W now corresponding to the inner wall of the shield, which the junction "sees," because radiant heat exchange occurs only between bodies that "see" each other. It will be recalled, however, that above linear velocities of about 300 fps, another source of error, due to conversion of kinetic energy of directed motion to thermal energy, must be considered. *See Sources and Evaluation of Errors.*

A water-cooled high-velocity probe used by the Bureau of Mines for measuring gas temperatures in large furnaces is shown in Fig. 8. The aspiration rate is adjusted to produce a mass velocity, G, (G = linear velocity times the density of gas at temperature) of 3 lb/(sq ft) (sec) through the shield. The radiation shields illustrated in Fig. 6 are employed.

Emissivity

The remaining factor amenable to control for reducing thermocouple errors is the emissivity of the junction and of radiation shields. For simplicity, emissivity is best described in terms of the character of a surface that is radiating heat. A smooth, bright, metal surface will have an emissivity of the order of 0.1 If the surface is rough or coated with an oxide, the emissivity increases rapidly and approaches 1.0 as a limit. For example, an oxidized iron or copper surface will have an emissivity of about 0.8. The effect of this emissivity range on the value of the second term of Equation 10 evidently is quite significant, and bright metal surfaces are to be preferred. However, it would be only under very unusual circumstances that such surfaces could be maintained: dirt, tarnish or other coatings on the junction soon increase its emissivity.

Conclusions

It is theoretically impossible to measure a gas temperature accurately unless the gas and its enclosure are at the same temperature. If there is a temperature difference between the gas and the walls of the enclosure, a thermocouple (or a thermometer) will be in error by an amount that depends upon the level of the higher temperature, the temperature difference, and the velocity of the gas past the thermocouple junction.

If the gases are less than about 500 F and have a linear velocity between 50 and 300 fps, a bare thermocouple, suitably immersed in the gas stream, will be reasonably accurate for most purposes.

For higher gas temperatures accompanied by gas-wall temperature differences greater than 50 degrees F, a high-velocity shielded thermocouple should be used to mini-

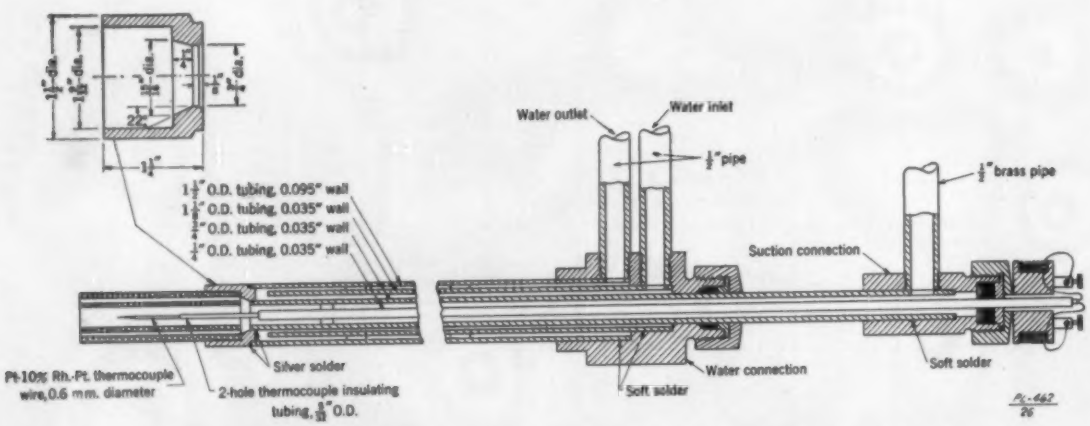


Fig. 8—Assembly drawing of water-cooled, high-velocity thermocouple probe

mize the thermocouple temperature error. The multiple-type radiation shield is to be preferred, but a properly designed single shield will give satisfactory results up to a gas temperature of about 1500 F. The rate of aspiration should be no less than 3 lb of gas per sec/per sq ft of free cross-sectional area of the shield.

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Summer Careers for Science Students

In an effort to meet its increasing demand for high-caliber technical graduates, the National Bureau of Standards is giving students an opportunity to become acquainted with a government research laboratory during their undergraduate summers, and discover the advantages of a professional career at the Bureau. Open to physical science and engineering majors and also to selected high school graduates who have displayed unusual scientific ability, the Student Trainee Program is proving mutually beneficial to the Bureau and the trainees. Approximately 150 students have been employed annually since the program was initiated in 1948. Besides carrying their share of the work load during the summer, many fulfill the ultimate aim of the program and later return to the staff in a permanent capacity.

To gain eligibility on the register from which appointments to the program are made, college men and women must pass a written Civil Service Examination for Student Trainees. At the high-school level a limited number of direct appointments are offered winners in the Westinghouse Science Talent Search and other science competitions. A student who has taken part in the program and is recommended by his supervisor may return each summer while he is completing his education. Participating in the program at the Washington laboratories for the first time this summer were 92 students, from 50 colleges, and 15 Science Talent winners. Of last year's 148 summer scientists, 80 returned to work this summer. At the laboratory in Boulder, Colorado, where the program has just been adopted, 42 trainees were employed.

Salaries are commensurate with the educational level of the applicant, ranging from $2690 to $3415.

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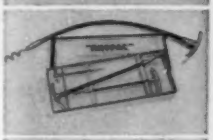

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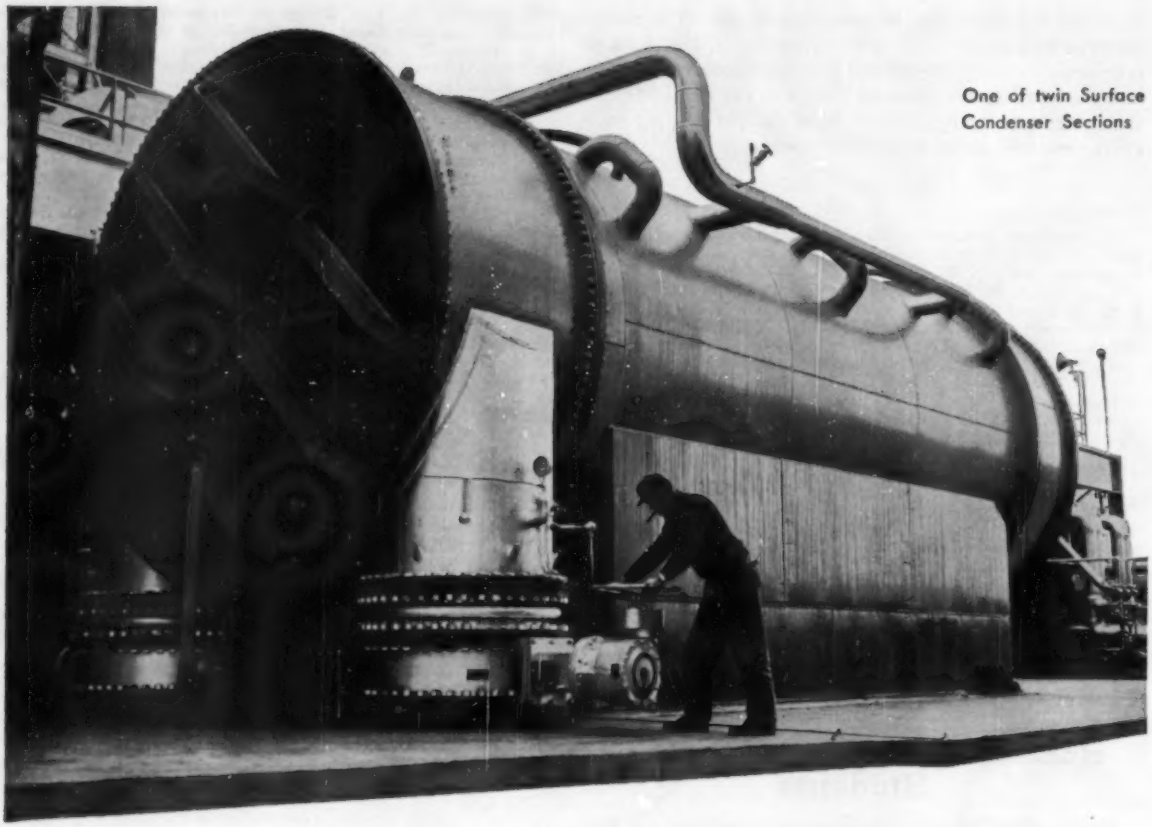

One of twin Surface Condenser Sections

Lummus Equipment Serves 110,000 KW Turbine For Texas Power and Light Company

Approximately 1 year ago, Lummus completed the installation of a 34,000 lb. per hr. evaporator, a 90,000 sq. ft. surface condenser and five feed water heaters, to serve a 110,000 KW turbine generator at the Collin Steam Electric Station of the Texas Power and Light Company.

The evaporator, designed by Lummus, is a high purity type which produces vapor of 1 ppm max. total solids purity, with a shell concentration of 3,000 ppm. It was furnished complete with a Lummus reflux condenser for producing condensate to be used on the bubble tray.

The Lummus-designed surface condenser is in two sections, joined by a common tee piece which connects to the turbine exhaust. The condenser is of the deaerating type producing an oxygen guarantee of 0.01 cc per liter.

The following Lummus feedwater heaters were furnished:

Item	Operating Pressure	Eff. Sq. Ft. Surface
Crossover Heater (Multilok)	2600#	6,745 sq. ft.
High Pressure Heater (Multilok)	2600#	6,490 sq. ft.
Intermediate High Pressure Heater	400#	2,850 sq. ft.
Intermediate Low Pressure Heater	400#	3,165 sq. ft.
Low Pressure Heater	400#	4,610 sq. ft.

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HEAT EXCHANGER DIVISION

Devising a Test for Plant Stack Stability*

By JACK SMITH†

Detroit Edison Co.

Stack deflection created by wind-induced vibration depends on the amount of damping in the stack and its support structure. With this amount known the maximum deflection under a given wind velocity can be calculated and possible damage prevented. Here is an experimental method of determining the amount of stack damping in the field.

ON December 18 and 19, following completion of the stacks for Units Nos. 1 and 2 at River Rouge Plant of the Detroit Edison Co. an unusual type of test was conducted on the stacks by the company's Engineering Laboratory and Research Department. The purpose of the test was to determine the amount of internal damping in the stacks and their supporting structure.

Damping is the internal friction, present to some degree in all structures, that always opposes motion, and thereby limits the amount that the structure can vibrate or sway when subjected to alternating forces. In the case of tall stacks, the alternating forces are produced by the wind.

Wind Forces on Stacks

When a steady wind flows across a cylindrical object such as a stack, the flow is not uniform on both sides. Instead, vortices (or whirlpools) are alternately formed and shed—first on one side and then on the other. The air-flow pattern produced by these vortices is shown in Fig. 1. Because a negative pressure is associated with the vortices, a pressure unbalance is created that acts alternately upon the sides of the stacks with a regular frequency. This causes the stack to vibrate or sway in a direction at right angles to the wind stream.

Observations and experiments on a number of stacks have indicated that the frequency or rate at which vortices are formed and shed is controlled by the motion of the stack, once motion is initiated. The frequency of the swaying motion under wind excitation always coincides with the natural frequency of the structure, which is usually about one cycle per second. Thus, the alternating wind force is always applied at resonance or in tempo with the swaying of the structure.

Actually, the force due to vortex formation is relatively small and, if applied continuously to one side of the stack would deflect it only a fraction of an inch. However, when this force is applied in exact tempo with the natural swaying motion of the stack, the deflection builds up with each cycle and can eventually reach serious proportions. An analogy is the manner in which a pendulum can be made to swing increasingly high with each stroke by giving it a slight push each time it swings through its mid-position.

The Importance of Internal Damping

The property that eventually limits the deflection of a stack is its internal damping. The greater the amount of damping in a stack and its support structure, the smaller is the deflection that can be caused by wind forces. If the exact amount of damping present is known, calculations can be made to predict the maximum deflection of the stack under any wind velocity,

The damping of any structure is dependent upon the

* Based on an article "A Discourse on the Virtues of Stack Twanging," Coal to Kilowatts, Detroit Edison Co. Production Dept. publication, June, 1956.

† Senior Research Engineer, Engineering Laboratories and Research Dept.

Fig. 1—Wind flow over a stack produces a vortex such as shown above in the air-flow pattern around a stack

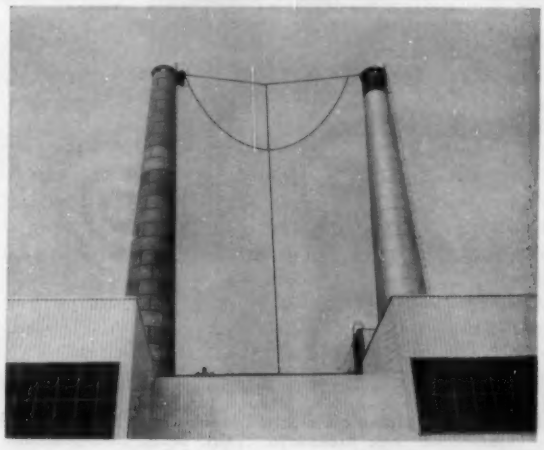

Fig. 2—A wire rope rigged between two stacks plus a connecting vertical line make it possible to apply various test deflecting forces

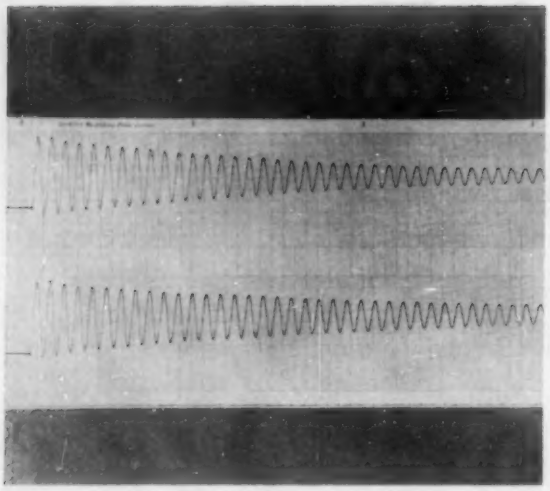

Fig. 4—Typical record of strains on structures underneath stacks discloses effects of the vibrations

Fig. 3—Instruments near base of stack recorded effect of vibrations and strains upon the stack and foundations

material, shape and type of fabrication. Thus, the damping in different stacks may be markedly different. The only way to accurately determine this quantity for a given stack is by experiment.

Tests on River Rouge Stacks

The tests conducted on the River Rouge stacks were part of a project undertaken to analyze the stability of the stacks under the most severe winds in this area.

The damping of the stacks was found by a test procedure popularly known as "twanging." The procedure consists of (1) the application of a horizontal force to the top of a stack sufficient to produce a measurable deflection, (2) a sudden release of the force which sets the stack into vibration, and (3) a continuous measurement of the rate of decrease of the vibration.

To apply the required force, a taut wire rope line was rigged horizontally between the two stacks as shown in

Fig. 5—Steel plates on unlined stacks have buckled under vibrations that measured 17-in. from mid-position

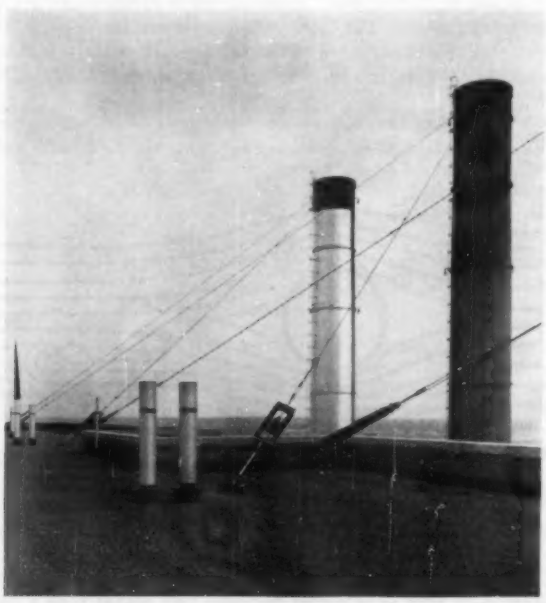

Fig. 6—Hydraulic shock absorbers installed in guy wires connected to stacks dampened out vibrations to cure Fig. 5

Fig. 2. This line was loaded downward at its mid-point by another line extending vertically downward. When a pull was exerted by a hoisting machine on the vertical line, a high tensile force was created in the horizontal line. This deflected the two stacks toward each other. When the tension in the horizontal line reached 60,000 lb, a calibrated notched tension bar separated, releasing the stacks suddenly and setting them into vibration. The subsequent motion of both stacks was continuously measured and recorded on oscillographs until it had completely stopped some three minutes later.

The instruments used for this purpose were small seismograph-type devices called accelerometers installed at the tops of the stacks. Other instruments recorded the strains in the stacks and their foundations, thereby disclosing the effects of the vibration upon the structures. Fig. 3 shows a part of the strain measuring instrumentation installed near the base of No. 1 Stack. Fig. 4 shows a typical oscillograph record of strains in the supporting columns beneath No. 1 Stack.

By determining, from the recorded data, the ratios of consecutive deflections as the vibration decayed, the amount of energy dissipated during each cycle through damping was established.

Experience with St. Clair Stacks

Materials like brick and concrete have much higher damping characteristics than steel. Much of the damping of a stack is believed, therefore, to come from its lining. Unlined steel stacks in the construction stage are especially susceptible to wind damage. We experienced such damage with St. Clair Stacks No. 1 and No. 2 in November 1953.

The all-welded steel shells of these stacks were completed, but the linings had not yet been installed when a wind storm swept through the area with wind velocities up to 65 mph. The stacks were observed to vibrate as much as 17 in. from their mid-positions at the tops. The stresses became so excessive that the steel plates of both stacks buckled and separated at the 200 ft. level. The damage is shown in Fig. 5. It was necessary to dismantle and rebuild these stacks. The revised stacks were shortened in height from 300 to 250 ft.

Following the completion of the revised St. Clair stacks, an investigation of their stability was undertaken by the Engineering Laboratory and Research Department. To determine their damping, field tests similar to the River Rouge tests were conducted. The results of the tests indicated that the damping was somewhat less than desirable. Therefore, as insurance against damage from wind excitation, external damping devices were installed on the stacks. These consisted of large hydraulic shock-absorbers incorporated in guy wires extending from the tops of the stacks to the boiler house roof as shown in Fig. 6. In the past two years, since these devices were installed, the stacks have been subjected to winds of up to 65 mph with no evidence of excessive wind-excited vibration.

Shippingport Reactor Vessel Shell in Transit

Tuesday, September 25, 1956, the shell of the 235-ton reactor vessel for the Shippingport, Pa. power plant of Duquesne Light Co., America's first full-scale commercial nuclear power plant, was shipped from the Chattanooga, Tenn., plant of Combustion Engineering, Inc. On hand to witness the loading of the heavy vessel and to inspect Combustion's new facilities for the manufacture of heavy nuclear components were about 150 representatives of the Atomic Energy Commission, government officials and many utility and business executives.

The completed reactor vessel was built by assembling sections of the heaviest clad plate ever rolled by Lukens Steel Company and by developing special welding, machining and heat-treating techniques at the Chattanooga shops of Combustion Engineering, Inc. The problems involved in the design, development, and manufacture of the unit were formidable, and were solved by close coordination between Combustion Engineering, Westinghouse and AEC engineers. These engineers had to rely upon fundamental theory to obtain many of the solutions. Accepted formulas for determining stresses and thicknesses, for example, were no longer applicable in a vessel with the thicknesses of plate and forgings involved. In addition to pressure and thermal stresses due to start-up conditions, consideration had to be given to heat generation in the vessel wall resulting from neutron and gamma ray flux emanating from the nuclear fission process. As a result of the design, development, and manufacturing experience on the reactor vessel, it is anticipated that new criteria and new formulas will be standardized in order to facilitate future design of this type of equipment.

The reactor vessel is designed to withstand a 2500-psig internal pressure at 600 F. At rated load 26 million lb of primary coolant water will enter the vessel each hour through four inlet nozzles and pass through the core where the temperature will be raised from 507 F to 542 F. Dry weight of the vessel is 235 tons, of which the shell portion weighs 150 tons and the removable top head 85 tons. In addition the vessel will contain thermal shields, a core assembly and other equipment having a total weight of an additional 100 tons. The internal diameter is 9 ft-1 in. and the length from the inside of the lower head to the inside of the top head is 31 ft-3 in.

The top head is fastened to the shell section by means of 42 6-in. diam studs, 80-$^1/_2$ in. long. Each stud with its accompanying nuts weighs 700 lb. To secure the head to the vessel shell, these studs are elongated by heat supplied from electric heaters extending into the center of the studs so that the nuts can be turned through a predetermined angle to induce the required stud tension when the studs cool to ambient temperature. The stud tension required to maintain contact of the mating surfaces of the head and shell under design conditions is 40,000 psi. Removability of the head is a design requirement to enable servicing of the internals of the vessel.

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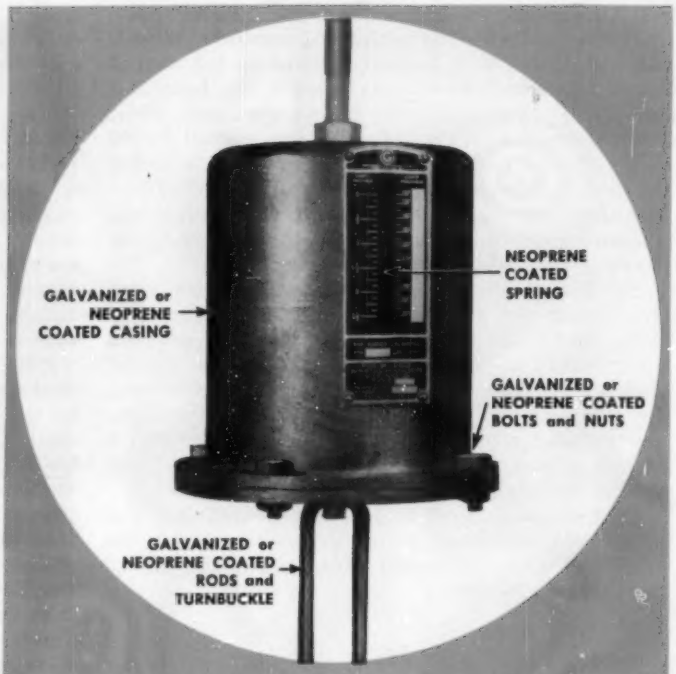
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Grinnell pre-engineered spring hangers are now offered in two new lines to meet the need for spring hangers in installations subject to highly corrosive industrial conditions and to severe weather exposure.

These hangers are the result of extensive experimentation with various coatings for Grinnell's standard pre-engineered spring hangers. In addition to providing flexibility in pipe suspension, they provide versatility of application through their corrosion-resistant characteristics. They are . . .

1. Neoprene coated — for highly corrosive conditions such as those found in chemical plants and refineries. *All* parts of the hanger are neoprene coated to protect the base metal from a wide range of corrosives. The flex life of the spring is unaffected by the neoprene . . . the coating resists cracking or flaking over a wide temperature range.

2. Galvanized — for outdoor installations where weather conditions are severe. All parts of the hanger are galvanized except the spring, which is neoprene coated to avoid alteration of temper, hydrogen embrittlement and decreased flex-life of the spring — usual hazards to springs from the galvanizing process.

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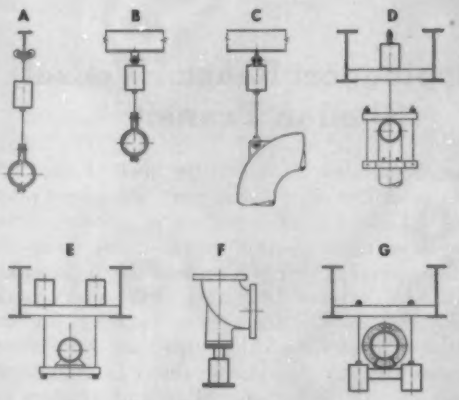

(A) Rod threaded to top cap (B) Furnished with single lug (C) Two lug style (D) Top adjusting (E) Adjustable top and bottom (F) For floor support (G) Trapeze assembly.

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18 sizes available from stock for load ranges from 53 lbs. to 12,000 lbs.

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Instrument Society Convenes In New York City

For the first time in its relatively short history the Instrument Society of America met in New York City and along with it staged its 11th Annual Exhibit, September 17–21. The Exhibit was excellent with displays by 425 manufacturers that attracted some 36,000 visitors. The individual exhibits were in the main well done, adequately staffed and designed.

Along with the Conference, where 100 technical papers were presented, the Society held a number of business sessions. At one of these sessions John T. Vollbrecht, president of Energy Control Corp., was elected national president of the Society to succeed Robert T. Sheen, president of the Milton Roy Co.

The 100 papers presented literally ran the gamut with many of them highly specialized in areas of rather remote interest to the power and steam generation fields. The fast-developing nuclear energy field and its control problems, however, drew a number of papers some of which we abstracted below. Similarly the more conventional steam and fluid-handling operations of interest to power men were given attention.

Nuclear Plants

Burns E. Woodward, General Electric Co., pointed out in his paper, "Instrumentation For A Nuclear Powered Electric Station" that the instrumentation for a nuclear powered electrical generating station will be similar to that of a conventional steam plant in many respects. The principal difference is the substitution of the instrumentation related to the nuclear reactor for the instruments of the fossil-fired boiler. Thus the controls and instrumentation for turbine, generator, steam and condensate handling equipment will be fairly conventional. The necessity for isolation and remote operation of some conventional equipment leads to somewhat more complex systems of instrumentation and control.

The new devices which are added to the basic plant are those for control of the nuclear process, and measurement of radiation for personnel and environmental protection. The nuclear reaction of the dual-cycling boiling water reactor is basically a stable process. A form of automatic feedback within the process makes possible wide fluctuations of controlled power level without change in control rod position.

Mr. Woodward discussed the manner in which instrument devices implement the control and described systems of reactor control and instrumentation.

The paper, "Instrumentation and Controls for the Homogeneous Reactor Test" by **D. S. Toomb, Jr.,** Oak Ridge National Laboratory, gave a very detailed accounting of instrumentation and controls for the second experimental aqueous reactor to be constructed under the Atomic Energy Commission program. Design of the instrumentation and controls system was heavily influenced by the need for extreme reliability. All components exposed to the process fluid are absolutely leaktight and radiation resistant.

Combustion Symposium Paper Abstracts

In the September issue of COMBUSTION relatively few of many papers held to be of interest to our readers were presented because of space limitations. The following represent the balance of these abstracts.

Effect of Pressure on Flame Propagation

An informal panel discussion on the effect of pressure on flame propagation was advanced by **R. S. Brokaw** and **Melvin Gerstein** of Lewis Flight Propulsion Laboratory of the National Advisory Committee for Aeronautics, **Mitchell Gilbert,** the Jet Propulsion Laboratory, California Institute of Technology, **Donald Smith** and **John T. Agnew,** Purdue University, and **E. S. Golvina** and **G. G. Fyodorov,** U.S.S.R. Academy of Sciences, Moscow, all authors of papers submitted to the Symposium. Their comments reflected their closeness to the problems of aviation combustion.

Brokaw and Gerstein expressed the belief that adiabatic flame temperature is a decisive factor in determining burning velocities, quenching distances and ignition energies. Although most of the experimental data are for a rather narrow range of initial temperatures, flame temperatures go from about 1800 to 3000 Kelvin. Certain correlations have been established that seem to hold well for mixtures close to the stoichiometric fuel oxidant ratio.

Mitchell Gilbert stated that in general the flame speeds of the faster burning mixtures were independent of pressure from a study of experimental data on eight fuels in the subatmospheric range. The dependence on pressure for the slower burning mixtures was not great, the maximum variation being of the order of $P^{-1/3}$.

Donald Smith and John T. Agnew expressed their comments based on stoichiometric proportions of methane and oxygen with varying amounts of nitrogen and argon as inert gas in a ten-inch bomb at pressures of 1, 2, 5, 10 and 20 atmospheres. The effect of surface-volume ratio was quite pronounced in their experiments not only with respect to values of burning velocity but with respect to ignition characteristics. There seems to be considerable evidence to indicate that not only propagation but ignition itself can be prevented by moderately high values of surface to volume ratios.

The Russians, E. S. Golovina and G. G. Fyodorov, based their investigations on the variations of the velocity of the chemical process by varying the oxygen content of a gas mixture of oxygen and nitrogen joining a mixture containing benzene, hexane and a hexene-hexane fraction. The oxygen-nitrogen mixture went from 16.4 per cent O_2 to 100 per cent O_2.

The experimental results have helped to establish that the maximum burning velocity in mixtures containing up to 50 per cent O_2 corresponds to the fuel and oxygen content ratio, constant for the given fuel, and is somewhat displaced to the region of lean mixtures at higher O_2 concentrations in the mixture. The lower concentration limit is constant and corresponds to a definite percentage of fuel in the mixture. The upper concentration limit of burning velocity for the given fuel with varying O_2 content in the mixture is likewise characterized by a constant value, which is not the value of the percentage of the fuel but the constant fuel and oxygen content ratio in the mixture. The maximum burning velocity depends in a linear way on the oxygen content in the mixture until the content reaches 50 per cent, after which the linearity is deranged. A similar treatment of the results obtained by **Jahn** has proved that this type of law is also true of other gases (CH_4, CO).

Structure and Propagation of Laminar Flames

R. M. Friston, Johns Hopkins University, in an invited paper entitled "The Structure of Laminar Flame Fronts" saluted the fact that experimental and theoretical investigations of the structure of laminar flames are playing a major rôle in advancing combustion research beyond the stage of empiricism and speculation.

Flame structure is generally used

to describe two properties of flames: the macroscopic structure or flame-front geometry and the microscopic structure as described by detailed temperature and composition profiles. Microscopic flame structure was the primary subject of this survey; however, flame geometry was discussed relative to the detailed microscopic structure. Several contributions to this field made since Dr. Gerstein's survey given at the Fourth Combustion Symposium were also covered.

Joseph M. Singer and **Guenther von Elbe,** U. S. Bureau of Mines, Pittsburgh, in their paper "Flame Propagation in Cylindrical Tubes near the Quenching Limit" described an apparatus for measuring flame speeds of downward propagation in tubes of near flame-quenching diameter and closed at the far end.

From a series of experiments the author felt that the burning velocity is not strongly depressed by the proximity of walls, even in channels approaching quenching dimensions, although the flame speed is strongly affected by channel size. Another observation of interest, the observed dead space (for methane-air mixtures) was compared with the interspace between luminous and schlieren traces of conical laminar flames in free air. The dead space near quenching in these experiments is roughly equivalent to the separation of luminous and schlieren images of conical flames at stoichiometric compositions but becomes much larger for lean and rich mixtures.

Experimental and Analytical Techniques

V. A. Popov, U.S.S.R. Academy of Sciences, Moscow, described a method employed to measure the temperature of freely falling, burning coal particles of spherical shape 4.5, 4.0, 3.2 and 2.4 mm in diameter in his paper "Method of Measuring the Temperature of Burning Fuel Particles in Motion."

The method employed the photopyrometric effect, i.e., the relation between the brightness temperature, T, of a body and the blackness, D, of its image on a photographic film. Since the analytical form of the characteristic curve D versus T is held difficult to predetermine a comparative method is used in photometry in which each piece of photographic material is calibrated against a standard specimen of known temperature. An exceedingly important circumstance, the author stressed, whose neglect leads to distorted results, is that the size of the standard calibration specimen must be equal to that of the object to be photographed. Any change in the dimensions of the object during temperature measurement and correction factors have to be applied. Special provisions were made to permit the application of the photopyrometric method to a moving body.

This method with its provisions was reported to determine not only the absolute value of the particle temperature but the change in the temperature as the particle moved downward. Under the condition of the experiment the temperature of the falling particles changed in certain cases from 885 C to 930 C. Temperature determinations are said to be accurate within an error of two per cent.

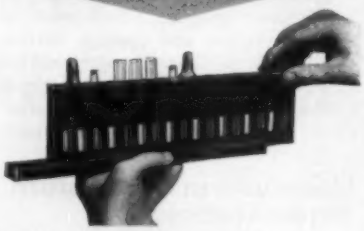
A paper "Thermoelectric Probes for Measuring High Temperatures in Gas Streams: Their Application to the Study of Flames Stabilized by Obstacles" by **G. Matton** and **C. Fourê,** Office National d'Etudes et de Richerches Aeronautiques, Seine, France, described a new type of thermoelectric probe. As the authors explain thermoelectric probes generally are used only up to 1200 C. Above this temperature, difficulties arise due to the behavior of the material, and lack of information as to the correction to be applied to the probe readings, depending upon its location. Finally, there may be undesirable catalytic effects. Optical methods are not always easy to apply and localization of the measurement is open to discussion.

As a result a special probe was developed with all of its elements cooled to below the temperature which limits its use. As the thermoelectric junction is cooled, the temperature indicated by the junction must have a reliable, simple and known relation to the real gas temperature. This was achieved by combining water-cooling of the entire probe, with internal sonic flow of gases at the height of the probe.

Probes of this type have been used in a systematic study of temperature as a function of: the structural parameters; the flow rate of the cooling water; and the pressure drop at the gas inlet. It appears that the temperature observed is independent of the rate of gas flow at the point where the reading is made and of radiation external to the probe.

The gas temperature taken as reference was supplied up to 1000 C, by a thermocouple that was carefully protected against radiation and conductivity. Up to 2000 C, it was obtained by an optical measurement according to Féry in the hot gas of a Meeker burner. In the absence of a suitable

ACCURATE pH, PHOSPHATE CONTROL with TAYLOR COMPARATORS REDUCES WASTE



Help determine EXACT amounts of chemicals needed for adjustments

By making accurate colorimetric tests of pH and phosphate content with Taylor Comparators, you can be sure of determining the exact amounts of chemicals needed to control scaling, corrosion and priming in boilers. Tests can be made in minutes—no experience is needed. Just fill test tubes with sample, add reagent to center tube and move color slide across until colors match. Even complete water analysis is only a little more detailed with the Taylor Water Analyzer.

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installation, the effect of absolute pressure in the flow where the reading is taken has not yet been studied.

The authors report found that: readings are sensitive enough to structural parameters to make it necessary to standardize each probe; the flow rate of the cooling water has no effect, within wide limits; the pressure drop at the gas intake can be disregarded once it is large enough for sonic flow at the neck.

Jessee F. Tryoler, Picatinny Arsenal, in his paper, "A Self-Calibrating High-Speed Photographic Pyrometer," advanced a pyrometer designed to measure the brightness temperature distribution of explosive phenomena as a function of time. It operates in a manner similar to an ordinary high-speed Fastax Camara, and can be used to obtain brightness temperature distribution up to a maximum rate of 2000 times per second, which is the limit of the particular camera used.

The instrument consists of a 35-mm, high-speed Fastax camera, a method for recording only "monochromatic" light and a calibrator. The function of the calibrator is to put stripes of various density along the edge of the film, each stripe simulating a specific brightness temperature.

In order to utilize only monochromatic light, a number 2412 Corning Glass cut-off filter is placed in front of the camera lens. The combined effects of the filter and the wave length sensitivity distribution of the Super XX film used in the instrument permits only "monochromatic" light to be recorded.

The calibrator consists of a tungsten filament lamp, a number 2412 Corning Glass filter of the same melt and stock thickness as the one placed in front of the camera lens, and a small collimating lens. The top of the calibrating device consists of a disk with three slits of different widths. Essentially the Fastax camera consists of a prism which rotates in synchronism with the sprocket wheel which drives the film smoothly but at a continually increasing speed.

The film runs across the calibrating disk in the direction of the slit widths. The lamp in the calibrating device is operated on a six-volt storage battery in series with a variable resistor and an ammeter. With the proper combination of lamp voltage and slit width, it is possible to obtain three stripes of different densities on the film. The filament is placed at the focus of the lens, so that small displacements in the film will have little effect on the densities of the stripes.

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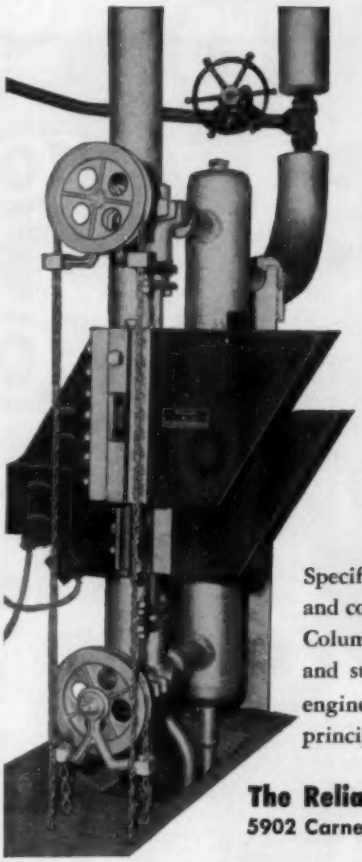

Since 1884, Reliance has maintained leadership in Boiler Safety Device development and manufacture. Water Columns with automatic Alarms, operated by the original *instantaneous* alarm mechanism, have helped to fortify power plants against the consequences of boiler water failure for billions of operating hours. Whistle alarms are available on columns for pressures to 900 psi; electric alarms, actuated by Reliance Electrode Levalarms, to 2500 psi.

For higher pressures — to 2500 psi — Reliance standard and custom-built equipment embodies principles of design and construction perfected in 70 years of *specializing* in this field—"super-rugged" Water Columns built with a generous margin of safety and tested at twice rated capacity.

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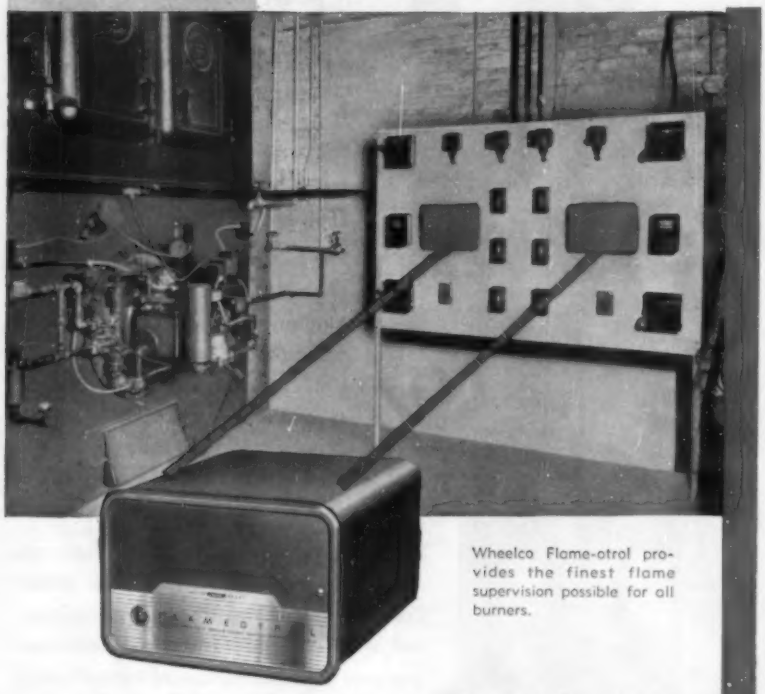
Here's Positive Protection Against Flame Failure— Specify Flame-otrol for Any Type Burner!



Wheelco Flame-otrol provides the finest flame supervision possible for all burners.

Wheelco Flame-otrol combustion safeguard systems offer unfailing, positive protection for any burner—gas, oil, or combination gas-oil.

One basic type, the Series 1470 Conductivity-Rectification system, uses the ability of a flame to conduct current to protect manually or semi-automatically ignited gas, oil, or combination fuel burners.

Series 1570 Infrared System, the other basic type, depends on the fluctuating current of a flame frequency for relay response. All Wheelco Flame-otrols offer the advantages of compact plug-in design, standard electronic tubes, heavy-duty construction, and other advanced features.

Your Wheelco field engineer can help you select the right flame supervision system, choosing from a full line of instruments and accessories. Call him today.

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The image exposures on the film for the stripes and for the phenomenon measured are inversely proportional to the speed of the film. These stripes correspond to densities of images for three different brightness temperature sources. The stripes are recorded at one edge of the film and the phenomena on the opposite side. The stripes are calibrated by taking pictures of several tungsten ribbon filament lamps at various known brightness temperatures in place of the phenomena, and interpolating the densities on the film to find the simulated temperatures. Once calibrated, the f number of the camera lens is fixed permanently and the voltage across the calibrating lamp is recorded.

If the phenomenon being observed has a higher brightness temperature than the calibrated stripes, a neutral filter, of known transmission at the wave length utilized, is placed in front of the camera lens in order to reduce the density of the image of the phenomenon to the range of densities of the stripes. The brightness temperature can then be calculated by an equation furnished by the author.

The "Application of Optical Methods to Combustion Research" was described by **F. J. Weinberg,** Imperial College, London. The author summarized recent advances in research carried out at the Department of Chemical Engineering of the Imperial College of Science & Technology, London, into the analytical applications of optical methods to combustion research. Up to the time of writing, the optical methods have been confined to those based on ray deflections and the combustion processes to premixed flames of simple geometry.

At the time of writing, the "partial interpretation" method is in use on two projects investigating the mode of action and the effect of gaseous inhibition and solid (alkali halide crystal clouds) inhibition. One of the quantities measured in the latter case is the fraction of the flame area occupied by "holes" caused by the solid crystals and their associated vapor spheres. The "complete interpretation" forms the basis of an attack on the mechanism of flame propagation. In this approach the variation of flame structure with initial temperature of the reactants is being investigated in lean flames and the highest degree of accuracy is aimed at by refinements of the optical technique. An investigation of the early stages of ignition by optical means is in hand.

In the immediate future it is in-

tended to extend the field of application to fast flames. These will include turbulent flames, which in the present state of theory appear to be a promising field of study.

Harold M. Brewster, Lt.jg, USNR, U. S. Naval Air Turbine Test Station, described the "Development of An Explosive Gas-Air Mixture Detector." The detector is used to sample areas, such as remotely located fuel rooms, and sea level and altitude gas turbine test facilities.

Available commercial detectors, based upon the principle of changing the resistance of one leg of a wheatstone bridge due to combustion of a gas sample about its surface, were evaluated and found to be unsatisfactory for determining the explosion hazard created by certain reciprocating and gas turbine fuels for the following reasons: (1) It would be necessary to evaluate the constituents of the fuel which vaporized to determine the potential for explosion from the detector readings obtained; (2) there is a possibility of fouling the active leg of the wheatstone bridge by certain of the fuel constituents.

Development of the present detector was initiated based upon published information which shows that the total heat content per unit volume of

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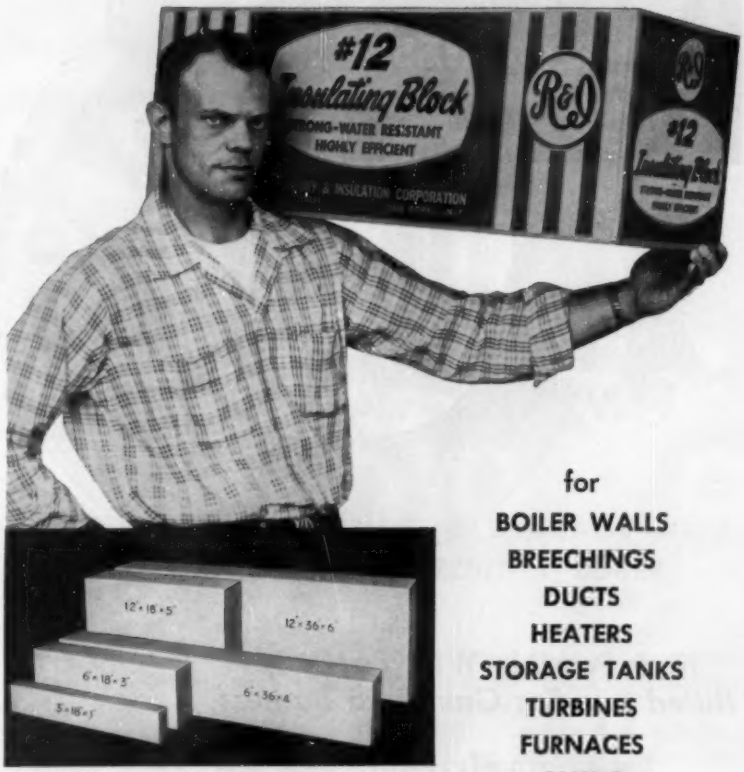

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Now Possible With Peabody Rifled Tile For Gas Fired Burners

Lost ignition need no longer worry users of gas-fired burners, even under the most adverse firing conditions. The new Peabody tile, specially designed and rifled in direct opposition to rotating air flow, in the rotating fuel and air mixture develops low-velocity eddy currents that give desired ignition. The protected burning eddies act as *a series of continuous and positive pilots* for the main body of the combustible mixture. This new tile permits *minimum load* setting of gas with rapid *maximum* settings of wind-box pressure *without loss of ignition!*

Available on new or old Peabody installations, the new Peabody Rifled Tile offers users unusually high efficiencies, plus unequalled dependability of ignition—under even the most adverse firing conditions. Write today for complete details.

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the fractions evaporating from reciprocating and gas turbine engine fuels at their lean explosive limit in air is practically the same.

The detector consists of a small combustor unit to which primary gaseous fuel and a sample from the area under investigation are delivered at continuous constant volumetric rates of flow. The flows have been adjusted so that the overall F/A ratio at a sample concentration equivalent to the lean explosive limit is less than stoichiometric. The mix is ignited and combustion is then self-sustaining. The combustor temperature rise is indicated on a pyrovane. When the temperature rise is of such magnitude as to indicate a sample strength of 25 per cent of the lean explosive limit, an alarm is activated.

Flammability, Ignition and Quenching

A theory is developed based on the concept that only a portion of the discharge energy is available for the ignition process in the "Spark Ignition of Flowing Gases Using Long-Duration Discharges" by **Clyde C. Swett, Jr.,** Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics. According to the author, the trends found for some of the parameters, such as pressure, temperature, fuel-air, and electrode spacing, are similar to those reported for ignition in quiescent mixtures; the trends of some of the other variables were determined to be as follows: Gas velocity and intensity of turbulence increase markedly the energy required for ignition; but scale of turbulence has negligible effect. The type of discharge, that is, arc or glow, affects the ignition energy required; the arc requires less energy than the glow discharge. This effect is attributed to less energy being dissipated at the cathode electrode for the arc discharge. The effect of electrode material is negligible if

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the type of discharge does not deviate from a glow discharge. Literature results that show the ignition energy to be affected by electrode material do not specify the type of discharge. This fact may account for the difference in results. An experimental method developed for obtaining the energy distribution along the discharge shows that $^1/_3$ to $^1/_2$ of the energy of the glow discharge is dissipated in a small region at the cathode electrode. This energy may be completely unavailable for the ignition process. Differences in energy distribution for long- and extremely short-duration discharges may explain why in some instances longer duration discharges require less energy for ignition than do the short duration discharges.

In another paper "Limits of Inflammability" by **J. W. Linnett** and **C. J. S. Simpson,** Oxford University, England, the authors point out that many experiments have been carried out to determine limits of inflammability but no detailed or complete theory of flame propagation has given an entirely satisfactory account, with experimental support, of the reasons for their existence. The simplest treatments involve the use of an arbitrary ignition temperature, one difficulty being replaced by another. There has recently been an attempt, however, to explain ignition temperatures in terms of branching chain reactions. These treatments are much simplified and it does not seem likely that they can provide a general explanation, because mixtures which almost certainly do not react by a branching chain mechanism show limits apparently not markedly different from those which do not involve branching chain reactions.

It has sometimes been questioned, the authors claim, whether fundamental inflammability limits do exist; that is, whether an infinite plane flame front would show a composition limit. The experiments in tubes of increasing diameter, and those with circular flat flames, do suggest that experimentally such infinite flames would show limits. However, it is undoubtedly true that conditions of curvature, direction of propagation and other circumstances of a similar kind do affect limits greatly.

366-2

THERE'S TRUTH IN THAT OLD ADAGE— WHEN YOU'RE TALKING ABOUT A BOILER.

Steel and water, by the very nature of things, are hardly the best of neighbors. Just as water can never *improve* boiler metal, so likewise it never loses its capacity to impair. Merely to hold the line challenges today's metallurgical and chemical knowledge . . . even as industry moves swiftly on to atomic power reality and its newer problems.

That's why today — fifty years after the first Apexiorized boiler went into service—consulting-engineer specifiers, boiler-insurance recommenders, and operating-engineer purchasers continue to look to Apexior Number 1 — the simple, brushed-on barrier that keeps steel and water good — and safe — neighbors.

No matter how well a boiler is operating — or how perfectly it is maintained — whether it be a large central-station steam generator, a small heating unit, or anything in between—Apexior Number 1 can make that good boiler better . . . for only Apexior makes any and all of these contributions to steaming performance. . . .

- an end to high-heat oxidation
- no chemical bonding of deposits
- maintenance of high heat transfer
- a good barrier for chemical cleaning
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- high resistance to oxygen
- full resistance to boiler water chemicals
- corrosion immunity
- gun-barrel smoothness, for excellent wetability

Before you order a new boiler, or take an old one off the line — let us bring you up to date on Apexior.

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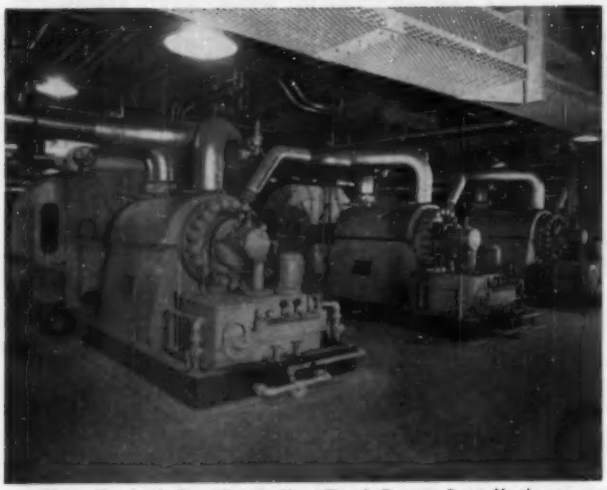
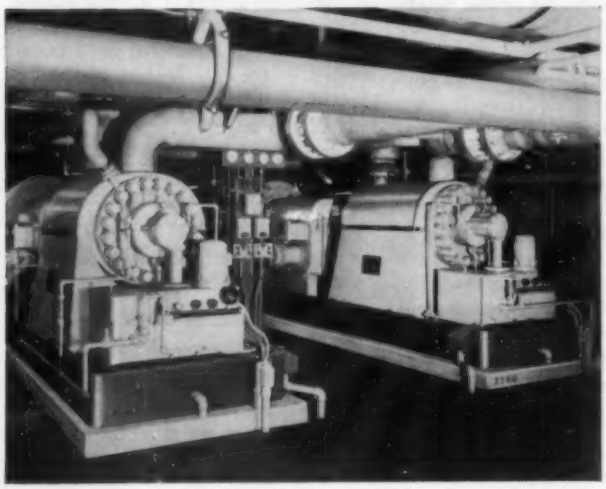


▲ Two Typical Pacific Boiler Feed Pump Installations ▼



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General View of Tyrone Power Station
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Bartlett-Snow coal handling at Tyrone

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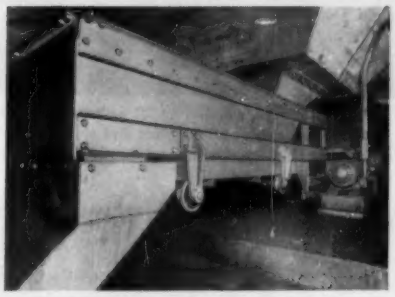

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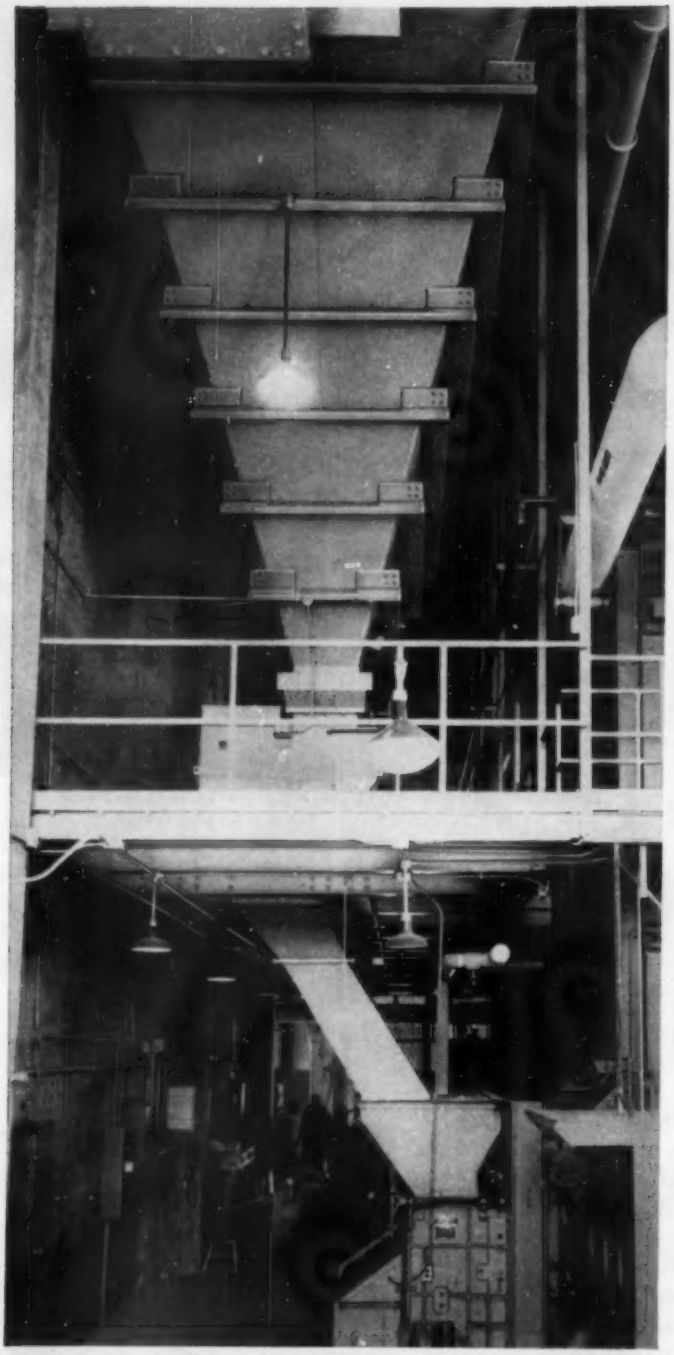

One more new installation of Lukens Type 304 *stainless-clad* steel — these smooth-operating coal hoppers and chutes, fabricated by Fairfield Engineering Company, Marion, Ohio, feed through second-floor scales to boiler.

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STEADY COAL FLOW A MUST IN NEW STATE HOSPITAL PLANT!

Hospitals can't take a chance on power interruptions from coal hangups. In Wisconsin's Mendota State Hospital, three *stainless-clad* steel coal hoppers and chutes, three-stories high, assure smooth, dependable coal flow. In more and more coal handling installations, clad steel is being specified because of these *demonstrated* advantages:

- Substantial economies from lower maintenance costs in chutes, hoppers, bunkers, pipes and spreaders.
- Freedom from hangups and the damaging and costly effects of sulfuric acid corrosion from wet coal.
- Toughness proved by *installations 10 years old which showed no measurable wear!*
- Evidence of service life that matches the life of the boiler!

PLUS: ready fabrication . . . permanence of bond between stainless steel cladding and strong, low-cost carbon steel backing . . . over-all quality that delivers lower maintenance costs, longer life, and trouble-free operation.

Bulletin 740 will give you performance facts and product information to help your engineers make the most of clad steel. For this bulletin, as well as the names of some of the nation's best and most experienced coal handling equipment builders, write Manager, Marketing Service, 845 Lukens Building, Lukens Steel Company, Coatesville, Pa.

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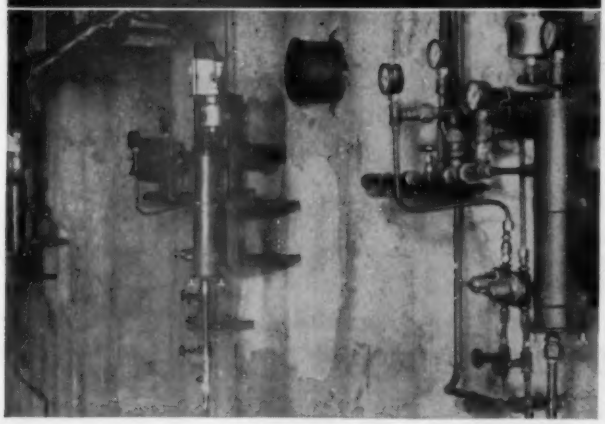

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■ Already, on some of the country's largest boilers, this new Speedomax O_2 System is enabling operators to trim excess air automatically to maintain combustion efficiency . . . and to do it with a certainty never before possible.

Why? As one operator put it, "The System gives me a record that's meaningful. When I look at this O_2 chart I know what's *really* happening—and I know it right away."

Behind this operator's confidence is the new L&N Multiple-Probe Sample Averaging Unit which *assures a more representative sample.* This unit maintains a true average from two, three, or more probes—even if individual sample flows drop 60 per cent. And excess air distribution across the duct can be checked right at the Averaging Unit.

There is also a new Reverse Jet Probe and Steam Sampler which delivers a *clean pressurized sample* even with the *dirtiest* of flue gases. Water jets flush the probe passage continually, steam ejector action pressurizes the sample, and steam condensing action plus centrifugal separation remove all dirt and acid.

And, in analyzing and recording, the speed of response of the Speedomax Recorder, coupled with the efficient operation of the L&N Magnetic O_2 Analyzer, increases speed and accuracy of O_2 analysis and recording even further.

Why not learn more about this new Speedomax O_2 equipment and what it can do for you? Write to Leeds & Northrup Company, 4972 Stenton Ave., Philadelphia 44, Pa.

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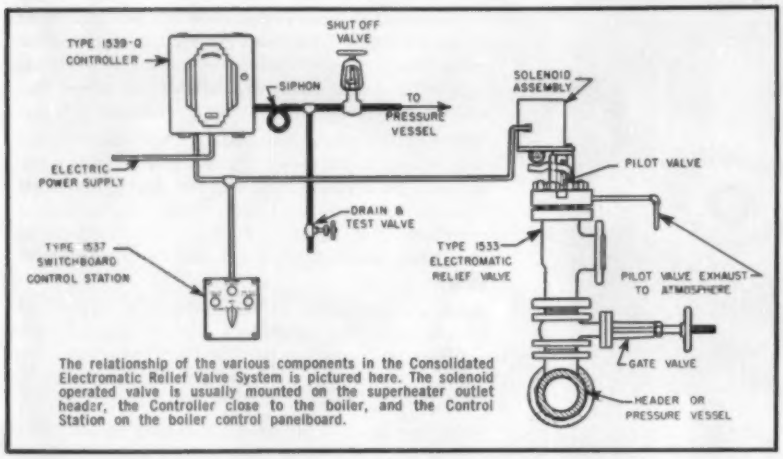
WITH THE CONSOLIDATED "ELECTROMATIC" RELIEF VALVE

The ideal auxiliary valve for steam generating plants with pressures to 2500 psi and temperatures to 1100° F., the Consolidated Electromatic Relief Valve relieves pressures precisely within close limits with "quick as a wink" cyclic action. It's an automatic, electrically actuated valve that can be accurately set for a differential of 1% or less between the opening and closing pressures.

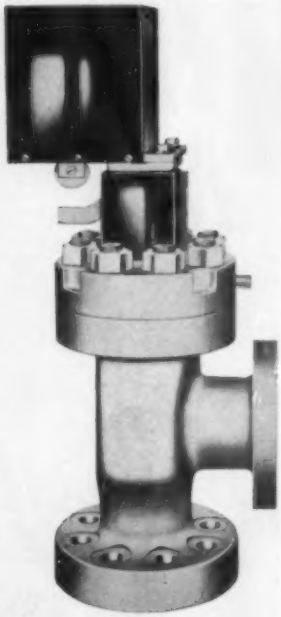
Operated by a solenoid actuated by a control station mounted in the panelboard, merely setting the switch provides automatic or manual service or cuts the valve out of operation. High superheat temperatures or other variables do not affect valve operation. A constant pressure output is maintained on the superheaters.

The Electromatic is also used to purge superheaters during start-up or as a superheater surge vent valve to reduce substantially the possibility of damage to equipment.

Wherever the Electromatic supplements spring-loaded safety valves, power is conserved, the efficiency of steam generating equipment is increased and maintenance is reduced. The Consolidated Electromatic Relief Valve is available in these sizes: 2½", 4", 10" and 14". Get complete specifications and operational details. Send for Bulletin 720.



The relationship of the various components in the Consolidated Electromatic Relief Valve System is pictured here. The solenoid operated valve is usually mounted on the superheater outlet header, the Controller close to the boiler, and the Control Station on the boiler control panelboard.



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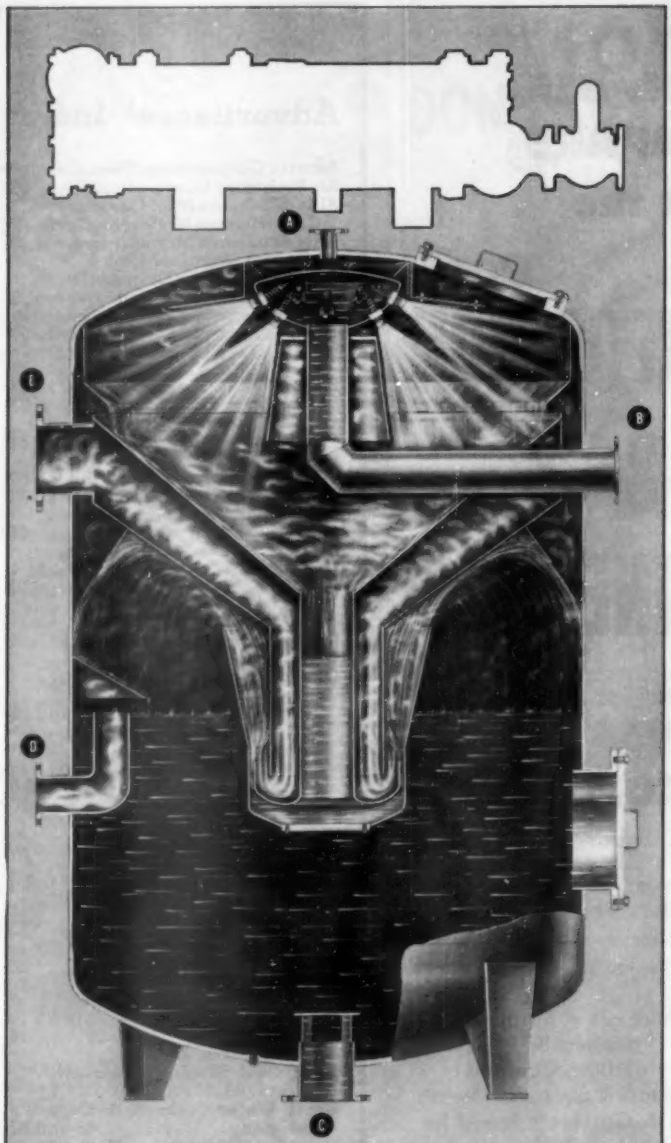

Full-contact deaerator needs no external vent condenser (white outline). The full-contact design effectively concentrates the vent-mixture inside the deaerator shell.

A Vent to atmosphere
B Water inlet
C Pump suction connection
D Overflow connection
E Steam inlet

WORTHINGTON

Now! Do away with deaerator maintenance

Here's a modern deaerator that eliminates most service problems because it has no vent condenser.

Virtually eliminates maintenance. Crammed up against the ceiling, vent condensers are difficult to inspect and clean. With a Worthington full-contact deaerator you eliminate this trouble and expense. For plants that normally operate around the clock, shutdown for deaerator maintenance is rarely necessary.

The carefully proportioned displacement flow path provided in the full-contact design concentrates the vent mixture by direct contact inside the deaerator shell. The vent condenser is no longer necessary.

Saves space. Headroom required by the deaerator may be cut by several feet—an important consideration in today's modern power plants where space is at a premium.

High efficiency. Like all Worthington deaerators, the full-contact unit is highly efficient at light as well as full load, as confirmed by numerous field tests.

Full-contact deaerators in various shell arrangements are available in capacities from 2,000 to 3,000,000 pounds per hour. Bulletin W-210-B32 has complete details. Incidentally, for the small power plant, Worthington builds a line of low-headroom deaerators that eliminate expensive elevated construction. For details, write to Section S66, Worthington Corporation, Steam Power Dept., Harrison, N. J. In Canada: Worthington (Canada) 1955, Ltd., Toronto, Ont. S-6.6

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Advertisers' Index

Aerotec Corporation, The..... *
Air Preheater Corporation, The 28
Allis-Chalmers Mfg. Company, Construction Machinery Div. *
Allis-Chalmers Mfg. Company, General Machinery Div..... *
American Blower Corporation. .....8 and 9
American Brake Shoe Company..... *

Bailey Meter Company..... 42
Baltimore & Ohio Railroad.... 27
Barber-Colman Co., Wheelco Instruments Div..... 64
C. O. Bartlett & Snow Company, The..... 69
Bayer Company, The..... 32
Blaw-Knox Company, Blaw-Knox Equipment Div..... 41
Buell Engineering Company, Inc..... 4
Buffalo Forge Company..... 10

Carborundum Company, The. *
Chesapeake & Ohio Railway... *
Clarage Fan Company..... *
Combustion Engineering, Inc. .....Second Cover, 20 and 21
Combustion Publishing Company, Inc..... *
Copes-Vulcan Div., Blaw-Knox Company.....2 and 3
Crane Company..... 18

Dampney Company, The..... 67
Dearborn Chemical Company. *
De Laval Steam Turbine Company..... *
Diamond Power Specialty Corporation.....13, Third Cover
Dowell Incorporated..... 25

Eastern Gas & Fuel Associates. 19
Economy Pumps, Inc..... 14
Edward Valves, Inc..... *
Enos Coal Mining Company, The..... *
Ernst Water Column & Gage Company.....65 and 67
Euclid Division, General Motors Corporation..... *

Fairmont Coal Bureau..... *
Flexitallic Gasket Company... 34
Foster Engineering Company.. 75

General Electric Company .....30 and 31
General Refractories Company..... *
Gifford-Wood Company..... *
Graver Water Conditioning Company..... *
Grinnell Company, Inc..... 60

Hagan Corporation..... 33
Hall Laboratories, Inc..... 33

(Continued on page 75)

Ingersoll-Rand Company..... *

Johns-Manville..... 26

M. W. Kellogg Company, The. 7
Koppers Company, The..... *

L. A. Water Softener Company. *
Leeds & Northrup Company... 71
Lukens Steel Company..... 70
Lummus Company, The..... 56

Manning, Maxwell & Moore, Inc..... 72
W. K. Mitchell & Company... *

National Aluminate Corporation..... 5
National Coal Association..... 15
National Exposition of Power & Mechanical Engineering..... 74
Norfolk and Western Railway. 6

Pacific Pumps, Inc..... 68
Peabody Engineering Corporation..... 66
Pennsylvania Crusher Div., Bath Iron Works Corp..... *
Pittsburgh Piping & Equipment Company..... 22
Powell Valves..... *
Prat-Daniel Corporation..... *

Refractory & Insulation Corporation..... 65
Reliance Gauge Column Company, The..... 63
Republic Flow Meters Company..... *
Republic Steel Corporation.... *
Research-Cottrell, Inc....16 and 17
Rhopac, Inc..... 55
Richardson Scale Company... 12

Standard Tube Company, The. 76
Stock Equipment Company... 23
Sy-Co Corporation..... *

W. A. Taylor and Co..... 62
Thermix Corporation..... *
Todd Shipyards Corp., Products Div..... *

Unafrax Construction Company..... 66

Walworth Company..... 24
Western Precipitation Corporation.....Fourth Cover
Westinghouse Electric Corporation, Sturtevant Div.... *
Westinghouse Electric Corporation..... 29
C. H. Wheeler Manufacturing Company..... 14
Worthington Corporation..... 73

Yarnall-Waring Company..... 11

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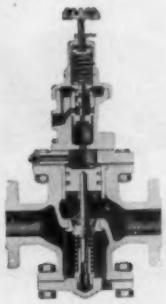

The Foster R-4 Relief Valve shown here is spring loaded, adjustable, with an internal pilot operated main valve. Single seated, tight closing and suitable for dead end service, it is designed for general service where practically instantaneous relief is required of the excess pressure with minimum build-up.

R-4 is only one of many standard Foster Relief Valves for all operating conditions and services.

For address of nearest Foster Representative, consult your Red Book, or get in touch with us direct, ask for Bulletin R101

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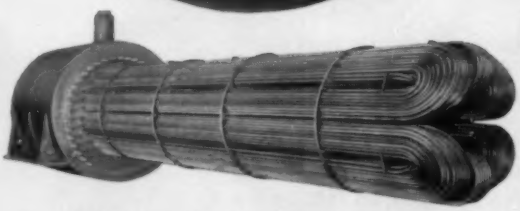

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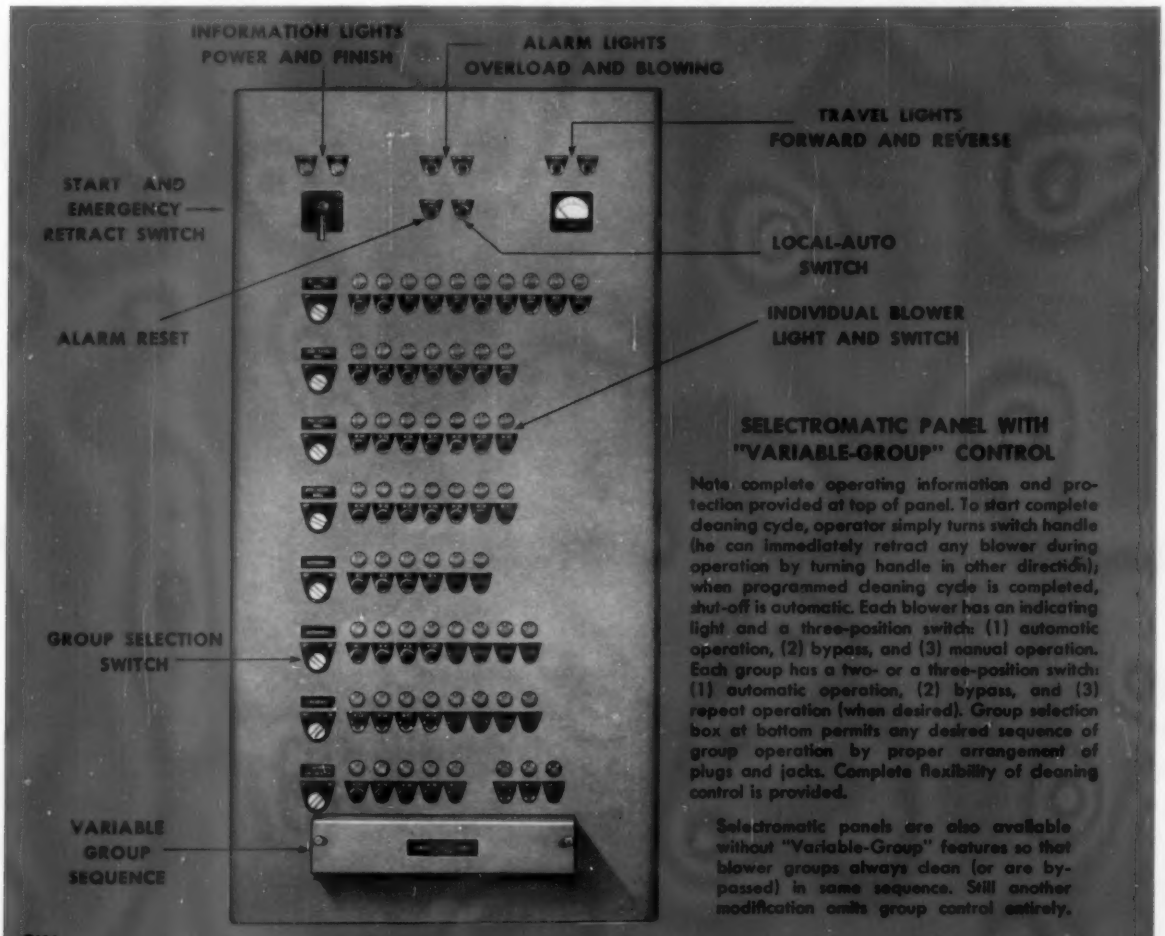
The Group concept can readily be arranged to have physical similarity to the boiler unit itself, with the groups starting at the lowest furnace level and progressing upward through the furnace wall blower levels and on through the superheater and reheater banks, economizer and air heater in logical group sequence.

A Diamond Selectromatic* Panel will provide the flexible blower control needed for the most efficient, economical and dependable cleaning of ANY boiler. The automatic sequential operation is easily and quickly changed to meet variable cleaning conditions in the unit. Operators know at all times the operating conditions of the blowers (see top of left page). Protective devices include automatic blower retraction on motor overload, blowing medium failure, and current failure (after restoration). Once a cycle is selected and initiated by the operator, no further attention is needed.

*Selectromatic is a registered trade mark that is a contraction of the functional features of these controls: selective—electric—automatic.



SELECTROMATIC PANEL WITH "VARIABLE-GROUP" CONTROL

Note complete operating information and protection provided at top of panel. To start complete cleaning cycle, operator simply turns switch handle (he can immediately retract any blower during operation by turning handle in other direction); when programmed cleaning cycle is completed, shut-off is automatic. Each blower has an indicating light and a three-position switch: (1) automatic operation, (2) bypass, and (3) manual operation. Each group has a two- or a three-position switch: (1) automatic operation, (2) bypass, and (3) repeat operation (when desired). Group selection box at bottom permits any desired sequence of group operation by proper arrangement of plugs and jacks. Complete flexibility of cleaning control is provided.

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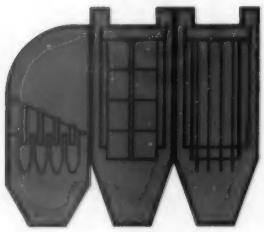

■ Western Precipitation was the first to combine Electrical and Mechanical recovery advantages in one compact, coordinated system—the CMP (Combination Multiclone—Precipitator) Unit. This equipment, offering almost constant collection efficiency despite varying gas volume, requires years of experience in both electrical and mechanical recovery methods for proper operating "balance".

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